DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 229

THE DISINFECTION OF SEWAGE AND SEWAGE FILTER EFFLUENTS

WITH A CHAPTER ON THE

PUTRESCIBILITY AND STABILITY OF SEWAGE EFFLUENTS

BY

EARLE BERNARD PHELPS

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THE DISINFECTION OF SEWAGE AND SEWAGE FILTER EFFLUENTS.

By Earle Bernard Phelps.

INTRODUCTION.

The investigations on which this report is based were conducted by E. B. Phelps at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology at Boston, Mass., and, in collaboration with Mr. Phelps, by Francis E. Daniels at the sewage-disposal works at Red Bank, N. J., and by Ezra B. Whitman at the Walbrook Testing Plant at Baltimore, Md., under cooperative agreements with the Massachusetts Institute of Technology, the State Sewerage Commission of New Jersey, and the city Sewerage Commission of Baltimore.

SEWAGE PURIFICATION.

PURIFYING AGENTS.

The essential agents of sewage purification are provided and employed by nature. The slow action of the soil bacteria, aided by atmospheric oxygen, eventually converts into harmless mineral ingredients all organic matter that comes within its sphere of activity, the process being analogous to that of combustion. Sewage purification as practiced to-day is but the intensive application of these natural processes under controllable conditions. The improvements that have been made in methods of treating sewage have not involved the discovery or application of new principles, but have merely increased the working efficiency of the natural bacterial agencies. The constant aim of the experimenters has been to increase the rate at which sewage can be treated on a given area of land. From the old-time sewage irrigation field, with its maximum capacity of possibly 10,000 gallons an acre in twenty-four hours, to the present-day trickling filter capable of dealing with two or three million gallons an acre a day, the march of improvement has been steady and continuous. The amount of sewage that can be purified on an acre of filtering area has been increased two or three hundred fold, and investigators are working toward a still greater increase.

It must be admitted that the significance of the word "purify" has also undergone a radical change. The effluents are no longer pure ground water. The liquid flowing from a modern trickling filter looks to the untrained eye like the original sewage. The organic matter of the sewage is no longer "burned up" to harmless mineral matter; indeed, there is almost as much organic matter in the effluent as in the raw sewage, and sometimes more. What change then has taken place to justify the use of the term "purified?" The answer lies in the fact that the organic matter has been changed but not removed. To carry out the simile, the organic matter, though not burned, has been charred or partly oxidized, and this charring process has been sufficient to rob it of its putrescibility or foulness. In other words, its chemical composition has been so altered that it is no longer capable of undergoing rapid putrefactive decomposition.

On first consideration it appears inconceivable that the chief object of sewage disposal—prevention of the fouling of streams—could be attained by such subtle changes in the nature of the organic matter. Nevertheless, effluents containing comparatively large amounts of organic matter may be discharged into streams without fear of causing nuisances if the organic matter is nonputrescible and if conditions preclude immediate sedimentation. The work of purification proceeds in the stream as it does in the soil until the oxidation, or combustion, is complete, oxygen for that purpose being sufficiently abundant in a reasonably clean stream. On the other hand, too much crude sewage added to water first robs it of all its available oxygen, then, in the anaërobic condition thus established, kills the beneficent oxidizing bacteria and transforms the stream practically to an open sewer. It is apparent, therefore, that purification of sewage has come to mean primarily the removal of its tendency to putrefy and not the total oxidation and removal of all its organic matter.

FATE OF BACTERIA IN SEWAGE FILTRATION.

In the older and more perfect methods of sewage purification the bacteria of the sewage with the other organic matter were destroyed by the straining action of the soil and the oxidizing action of the normal soil bacteria; but a modern filter of coarse stones neither strains the material nor affords opportunity for vigorous oxidation. Much of the original organic matter passes through such a filter, having undergone changes so slight as almost to defy detection by ordinary chemical means. It is reasonable, therefore, to inquire as to the fate of the sewage bacteria and particularly as to the pathogens, or disease-producing microbes. The data on this point are somewhat conflicting. The question was raised in 1893 in connection with the first septic tank at Exeter, England. The fear was expressed that pathogenic germs might even multiply in the tank, as other forms of bacteria are known to do. Sims Woodhead conducted an investigation as a result of which he concluded that no organisms capable of setting up morbid changes in animals after inoculation came from the tank. Pickard introduced an emulsion of typhoid bacilli into the Exeter tank and observed a slow diminution in number. It is important to note, however, that even after fourteen days 1 per cent of the original number was still alive. Pickard also reported a removal of over 90 per cent of the typhoid organisms introduced into a contact filter. Rideal, on examining the effluents of three Scott-Moncrieff filters at Caterham, England, found reductions in *Bacillus coli* ranging from 95 per cent to 98.5 per cent. He made the following statement before the Royal Sewage Commission:[a] "Satisfactory evidence in most of the systems is now available from which I think we are justified in concluding that even if towns on a river like the Thames adopted bacterial schemes the pathogenicity of the London water supply would not be adversely affected thereby."

On the other hand, there is some evidence that the pathogenic properties of sewage are not materially altered in its passage through a coarse-grained filter. Alfred MacConkey[b] made a series of tests upon the longevity of *B. typhi* in various waters. Samples of the liquid under examination were inoculated with large numbers of typhoid bacilli and were kept under observation. In one experiment the organism was isolated from sewage thirteen days after inoculation. In a second set of two tests it was not found after fifteen and after seventeen days. In two contact-bed effluents it was found after fifteen and seventeen days, respectively, while in two other contact-bed effluents it did not survive beyond the sixth day. MacConkey concluded that the numbers of typhoid organisms reaching a filter are ordinarily so small that there is but slight possibility of their passing through, but "if from any cause they arrive to the tanks in such large numbers as the *B. coli*, then certainly they might appear in the effluent just as the *B. coli* does." In interpreting such results due allowance must be made for the fact that the isolation and identification of the typhoid bacillus under such conditions is extremely difficult and that failure to detect the organism carries much less experimental weight than a positive result.

Houston,[c] in a careful investigation of the subject for the Royal Sewage Commission, found that the effluents from septic tanks, contact beds, and trickling-filter beds contained enormous numbers of

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[a] Interim Rept. Royal Sewage Commission, 1901, Question No. 4148, p. 251.

[b] Second Rept. Royal Sewage Commission, 1902, p. 62.

[c] Houston, A. C., Second Rept. Royal Sewage Commission, 1902, p. 26.

bacteria. In some of the tests the per cent reduction in the effluents as compared with the raw sewage was striking; but as it was necessary to judge an effluent by its actual condition, and as the number of micro organisms still remaining was almost always very large, he concluded that per cent purification is of minor importance. In not a few of the tests the bacteria were practically as numerous in the effluent as in the raw sewage. The relative abundance of the different kinds of bacteria appeared to be much the same in the effluents as in the crude sewage. Of undesirable bacteria, such as *B. coli*, proteus-like germs, spores of *B. enteritidis sporogenes*, and streptococci, the effluents contained nearly as many as the crude sewage. The reduction in numbers of these objectionable bacteria was apparently not marked enough to be of consequence from the point of view of the epidemiologist. No definite proof was found that the effluents from bacterial beds were conspicuously safer than crude sewage in their possible relation to disease. Attention was especially called to the presence of streptococci in the effluent. Houston contends that if it be true that streptococci are more delicate germs than the typhoid bacillus, their presence in large numbers in the effluent indicates the possibility or probability that the typhoid bacillus also survives under similar conditions—a view that leads to the inference that the biological processes at work are not strongly inimical, if hostile at all, to the vitality of pathogenic germs. Experiments with *B. sporogenes*, a spore-forming organism, have shown that it passes through filters in almost undiminished numbers.

Besides the facts already mentioned, little information is available which bears directly on the fate of the pathogens, and particularly of the typhoid organism, in sewage purification. It is therefore necessary to examine the available indirect evidence. By studying the removal of certain specific organisms that are easily detected and certain well-defined groups of organisms existing in sewage, the probability of the elimination of the typhoid organism can be determined. In the absence of further data it must be assumed for the sake of safety that the elimination of the typhoid bacillus is not materially greater than that of the other species and groups that may be studied. During the summer of 1904 there were operated at the sewage experiment station four septic tanks running at storage periods of from twelve to forty-eight hours, nine contact beds differing in material, depth, and rate, three trickling filters, and three sand filters, one of each set being run with crude sewage and two kinds of septic effluents, respectively. The results of bacterial counts are shown in Table 1, in which the numbers are averages of all results obtained with one kind of filter.[a]

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[a] Winslow, C.-E. A., The number of bacteria in sewage and sewage effluents: Jour. Infect. Dis., vol. 1, Suppl. 1, 1905, p. 209.

TABLE 1.—*Bacteria in sewage and in effluents of sewage filters at Boston in 1904.*

[Winslow.]

Source of sample.	Number of examinations.	Bacteria per cubic centimeter.					
		Lactose gelatin at 20° C.			Lactose agar at 37° C.		Anaërobic agar.
		Liquefiers.	Acid formers.	Total.	Acid formers.	Total.	
Sewage	56	365,000	1,670,000	5,430,000	1,670,000	3,760,000	2,440,000
Septic effluent	56	162,000	495,000	1,750,000	650,000	1,040,000	930,000
Contact filters	140	60,000	270,000	1,060,000	290,000	570,000	440,000
Trickling filters	18	134,000	114,000	451,000	284,000	1,170,000	200,000
Sand filters	15	500	1,360	9,160	11,400	43,600	1,200

The septic tank and two trickling filters in operation at the same station during the summer of 1906 gave the average results recorded in Table 2, showing that less than one-half of the bacteria growing at 37° C. were removed by filtration, and that the reduction in the number of colon bacilli was practically in the same proportion.

TABLE 2.—*Bacteria in sewage, septic effluent, and trickling-filter effluents at Boston in 1906.*

Source of sample.	Bacteria per cubic centimeter; lactose agar at 37° C.	B. coli; positive[a] tests in one-millionth of a cubic centimeter.
		Per cent.
Sewage	1,300,000	65
Trickling filter receiving sewage	750,000	35
Septic effluent	1,650,000	66
Trickling filter receiving septic effluent	750,000	35

[a] The bile broth presumptive test recommended by D. D. Jackson was employed.

Johnson,[a] in his experiments at Columbus, found a reduction in the total number of bacteria ranging from 33 per cent to 60 per cent in primary-contact filters, and a removal of about 39 per cent of the remainder in secondary-contact filters, and from 30 per cent to 80 per cent in trickling filters, depending largely on the depth of the filter. Subsequent sedimentation increased this removal to 87 per cent. Thumm and Pritzkow,[b] at Berlin, report a reduction in the number of bacteria from 17,000,000 in the sewage to 6,000,000 in the effluent of a double-contact filter. At La Madelein, France, Calmette[c] found 5,000,000 bacteria per cubic centimeter in crude sewage, 2,900,000 in a secondary-contact effluent, and 800,000 in the effluent from a trickling filter. The sewage contained 20,000, the contact effluent 4,000, and the trickling effluent 2,000 colon bacilli. At Plainfield, N. J., the

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[a] Johnson, Geo. A., Report on sewage purification at Columbus, Ohio, 1905.

[b] Thumm, K., and Pritzkow, A., Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, 1903, vol. 2, p. 127.

[c] Calmette, A., Recherches sur l'epuvation des eaux d'égout, Lille, 1907, vol. 2.

double-contact filter was found to reduce the number of bacteria from an average of 1,000,000 per cubic centimeter to an average of 322,000; *B. coli* ranged from 1,000,000 to 100,000 in the sewage and from 100,000 to 10,000 in the effluent.[a] An experiment performed by Houston [b] is important in this connection: *B. pyocyaneus*, a pathogenic organism, was applied to the top of a trickling filter, and ten minutes later the bacillus appeared in the effluent, continuing to be discharged for ten days. In a similar manner the same organism was found to pass through a septic tank and a contact filter successively, and to persist in both for nine days. At Baltimore, Md., the board of advisory engineers concluded that 95 per cent of the bacteria in the sewage could be removed by a system comprising a septic tank, 9-foot trickling filters, and supplementary sedimentation basins.[c] Such results are better than those usually obtained elsewhere, and if they can be maintained in practice they will go far toward solving the problem in that locality.

From a consideration of the available evidence it may be stated in a general way that coarse-grained, rapid sewage filters remove a considerable proportion of the sewage bacteria; that such removal has not been found to be sufficiently complete in practice to have great sanitary significance; that bacteria of various groups and certain specific organisms pass through such filters in practically the same proportions as the bacteria as a whole; and that, in the absence of any information to the contrary, it should be assumed that such filters have no greater effect on the typhoid and other pathogenic organisms than on *B. coli*, *B. pyocyaneus*, sewage streptococci, or the different groups of sewage bacteria.

THE NECESSITY FOR DISINFECTION.

It is probable that removal of bacteria will again be considered an essential factor in sewage purification. That it was so considered formerly is well known. The development of the modern rapid filter has made it possible to introduce sewage purification under conditions where it would have been impossible or prohibitively expensive in former days. In the acceptance of a partial solution of the problem much has been gained and but little lost. The process of purification that renders practically stable the offensive organic matter of sewage has accomplished the most important and in many cases the only essential requirement. If, however, sewage effluents find their way into the drinking waters of neighboring communities, the question of the relative responsibility of the settlements is debatable. It is generally conceded at present that efficient sewage purification should be

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[a] Rept. Sewerage Commission of New Jersey for 1906.

[b] Houston, A. C., Fourth Interim Rept. Royal Sewage Commission, 1904, vol. 3, p. 77.

[c] Report of the Board of Advisory Engineers to the Sewerage Commission of Baltimore, 1906.

undertaken by the communities in which the sewage originates, and that purification of the water supply is the urgent duty of the other communities. As streams flowing through populous districts are necessarily contaminated and unfit for domestic use without filtration, it is considered unjust to require a community to purify its sewage to a higher degree bacterially than that shown by the stream into which it is discharged. On the other hand, in the fight against infectious diseases, sound tactics demand an attack on the enemy as near as possible to the initial source of infection. The best and easiest place to destroy typhoid germs is at the bedside of the typhoid patient; but this method can not be relied on to keep sewage free from infection, and the next strategic point is certainly the sewage. Once at large the germs may reach their victims in a score of well-known ways, and who will say by how many devious and unknown paths? With increasing knowledge of these facts and with improved processes and reduced cost of disinfection it is not too much to expect that the disinfection of sewage will some day be regarded as an integral part of its purification and as a necessary measure of protection for the community.

One of the ways by which typhoid germs pass from the sewer to the victim is by means of shellfish fed or fattened in polluted water, and many of the oyster and clam beds of the eastern seaboard are subject to pollution by sewage. In England conditions are so serious that the demand for shellfish has perceptibly decreased. The situation presents obvious difficulties. The water of a polluted river may be rendered potable through filtration, but the purification of shellfish seems to be out of the question; it follows, therefore, that health must be safeguarded either by preventing the discharge of the bacteria of sewage on shellfish beds or by prohibiting the taking of the shellfish. In a large community where the shellfish industry is small it will probably be more satisfactory to adopt the latter method, but in small communities whose sewage pollutes large and important beds thorough bacterial purification is not an unreasonable requirement. Unfortunately the greatest shellfish areas of the country are situated near large cities, where they are subject directly or indirectly to possible pollution from sewage discharge.

In a carefully prepared paper on the pollution of shellfish beds, G. W. Fuller[a] states that the annual crop of oysters gathered along the Atlantic and Gulf coasts in 1902 amounted to more than 25,000,000 bushels, exceeding in value $13,000,000, and that the crop of clams was more than 2,000,000 bushels, valued at $2,000,000. Over one-half of this total production came from New Jersey, Maryland, and Virginia, and the shellfish were grown mainly in the

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[a] Concerning sewage disposal from the standpoint of the pollution of oysters and other shellfish, with especial reference to their transmission of typhoid fever: Jour. Franklin Inst., vol. 160, 1905, p. 82.

waters of Delaware and Chesapeake bays, which receive the sewage from many large cities. At present this sewage is so enormously diluted by the bay waters that the danger of pollution is in most places remote, but it is present and ever increasing.

In Baltimore a system of sewerage and sewage disposal is being planned to remedy the already serious pollution of Patapsco River. In calling on a commission of experts for advice the sewerage commission of Baltimore specified "that the effluent proposed to be discharged into Chesapeake Bay or its tributaries in the system to be recommended by the engineers shall be of the highest practicable degree of purity." [a]

By agreement between the States of New Jersey and Pennsylvania the condition of Delaware River has been thoroughly investigated, and the pollution of that stream by sewage from Trenton, Bordentown, and other smaller communities in New Jersey, and Philadelphia, Easton, and other Pennsylvania cities, is prohibited after certain specified dates.[b] The necessity for protecting these valuable shellfish beds makes bacterial removal an essential feature in any scheme of sewage disposal which may be considered for such places.

The board of advisory engineers at Baltimore recommended that the settled trickling-filter effluent be given a final treatment on sand filters. The cost of works for the complete treatment of 75,000,000 gallons of sewage a day by septic tanks, trickling filters, sedimentation basins, and sand filters was estimated at $3,283,250, of which sum $1,040,750, or over 31 per cent, was for supplementary treatment. The annual cost of operation is expected to be $115,500, of which $55,000, or 48 per cent, is for supplementary treatment. This gives some idea of the cost of complete bacterial removal by filtration processes over and above the cost of reasonable organic purification. In regard to disinfection by chemical means the advisory engineers state: "To remove all bacteria remaining in the settled effluent from the sprinkling filters by disinfectants, such as hypochlorite of lime or of sodium or sulphate of copper, would be prohibitively expensive"—an authoritative opinion based on the best evidence then to be had. Almost no American data on chemical disinfection were available, and the results of experiments in Germany indicated that such disinfection could be accomplished only at high cost. The patented processes mainly used in England were also expensive. It was therefore desirable to learn just how effective disinfection processes could be made under conditions in America—how much they would cost, and what after effects, objectionable or otherwise, might follow their introduction.

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[a] Report of the Board of Advisory Engineers to the Sewerage Commission of Baltimore, 1906.

[b] Rept. New Jersey State Sewerage Commission, 1907.

A review of the available data and a short experimental investigation made in 1906 at Boston[a] led the writer to believe that there is much value in the process and that it might afford the best possible solution of the whole problem under certain conditions common in this country, particularly in localities where the shellfish question is involved.

METHODS OF DISINFECTION.

CLASSIFICATION OF METHODS.

In Great Britain the somewhat indefinite allusions of the royal sewage commission to sterilization as a finishing process in sewage treatment aroused a storm of discussion that resulted, at least, in clearing away many misconceptions. Sterilization processes of many kinds have been investigated, and the subject has been freely discussed. For the following classification of sterilizing agents and for many of the facts noted here the writer is indebted to Rideal,[b] whose carefully prepared paper on the subject discusses its possibilities in a thoroughly impartial manner. Other authorities are cited wherever possible. Except when otherwise stated, costs are based on current prices in eastern markets.

The different methods and substances proposed for the sterilization of effluents are considered in the following order:

1. Heat.
2. Lime.
3. Acids.
4. Ozone.
5. Chlorine and its compounds.
    (*a*) Chlorine gas.
    (*b*) Hypochlorites, or oxychlorides.
    (*c*) Electrolytic chlorine processes.
6. Copper and its compounds.
7. Miscellaneous.
    (*a*) Permanganates.
    (*b*) "Amines" process.
    (*c*) Sodium benzoate and other organic compounds.

HEAT.

The use of heat has been suggested for disinfecting sewage. In his testimony before the royal sewage commission E. E. Klein[c] referred to a patented process which he considered practicable, by the use of which sufficient ammonia could be recovered from the sewage nearly to pay for the treatment; but there is no record that this process

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[a] Phelps, Earle B., and Carpenter, William T., The sterilization of sewage-filter effluents: Tech. Quart., vol. 19, 1906, p. 382; Contributions from the Sanitary Research Laboratory, vol. 4, 1908.

[b] Rideal, S., On the sterilization of effluents: Jour. Royal Sanitary Institute, vol. 26, p. 378.

[c] Interim Rept. Royal Sewage Commission, 1901, question 9674, p. 519.

has ever been used on a working scale. A device for heat interchange similar to that employed in the Forbes sterilizer may possibly, as is claimed, raise water to the boiling point and cool it again within 5° F. of the initial temperature. With coal at $3 per ton having a calorific value of 10,000 British thermal units, the fuel cost alone of such an operation would be about $7 per million gallons of sewage. The ammonia in a million gallons of Boston sewage, if in the form of sulphate, would have a market value of $20. Whether the difference between the value of the ammonium sulphate and the cost of the fuel is sufficient to cover the cost of operation, including labor, evaporation of the dilute solution, and all fixed charges can be determined only by actual experiment, but the plan is not wholly without possibilities.

LIME.

Caustic lime acts only slightly as a germicide, and the considerable removal of bacteria that takes place when lime is used as a precipitant in sewage is undoubtedly due to the action of the precipitate itself in dragging down with it the bacteria which it has entangled. Such action occurs to some extent in the precipitation of any substance, and even the sedimentation of sewage is always accompanied by reduction in the numbers of bacteria. Lime alone, therefore, would be of little value for sterilizing effluents. Rideal states that 60 to 70 grains per imperial gallon (860 to 1,000 parts per million) are inefficient in sterilization. Thresh, however, believes that lime would produce a satisfactory sterilization of effluents.[a]

ACIDS.

Most bacteria, and particularly typhoid and cholera germs, are more readily destroyed by acids than by alkalies. Rideal, therefore, considers it feasible to employ acids as germicides. He states that Stutzer found 0.05 per cent acid solutions fatal to bacteria in twenty-four hours; that Ivanoff found that 0.04 per cent to 0.08 per cent of acid destroyed the cholera germs in the sewage of Berlin and of Potsdam; that Kitasato found 0.08 per cent of sulphuric acid fatal to typhoid bacilli in fifteen minutes, and that he had himself obtained similar results. To furnish 1,000,000 gallons of sewage with 0.08 per cent of sulphuric acid requires 6,650 pounds of acid, costing approximately $73. Smaller amounts of acid might be used, as it would be unnecessary to kill typhoid germs in so short a time as fifteen minutes; but, on the other hand, most sewage contains a considerable amount of free alkali which must be neutralized before any germicidal effect of

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[a] Interim Rept. Royal Sewage Commission, 1901, question 8917, p. 502.

the acid would be obtained. This process consequently would seem to be impracticable except in emergencies. It is interesting to note that the sewage of Worcester, Mass., contains normally an average of 0.01 per cent of free sulphuric acid, or half enough to kill cholera germs in twenty-four hours.

OZONE.

Ozone has been used more or less successfully in Germany, particularly at Weisbaden, for sterilizing drinking water. Though the process has been most favorably commented on by those in immediate charge of the investigations, it has not been generally regarded as successful. The possibility of procuring a satisfactory effluent by this process, when the water is that of a highly-polluted river is beyond question, but whether the process can satisfactorily treat a sewage effluent of considerable turbidity has not been determined. Rideal calls attention to the fact that ozone is but sparingly soluble in water, and on that account it might fail to penetrate the solid masses in the effluent, since the rate at which a dissolved gas will penetrate solids in a liquid is a direct function of its solubility. The principal cause of failure of the ozone process, however, seems to be its expense. If this be true in waterworks it is hardly possible that such treatment could be applied to sewage effluents as an additional safeguard after purification. Data are not at hand for estimating the cost of applying ozone treatment to sewage effluents, but besides the cost of operation there is the very considerable cost of installing the necessary machinery and towers.

CHLORINE AND ITS COMPOUNDS.

GERMICIDAL ACTION.

Chlorine is well known as a powerful germicide. As a bleaching agent it acts on organic coloring matter indirectly by means of the free nascent oxygen which it liberates from the water in which it is dissolved, and it is probable that its germicidal action is similar. In other words, chlorine and ozone owe their germicidal power to the same thing—nascent oxygen. Chlorine, however, has the advantages of being cheap, of being more readily soluble, and of being obtainable in compounds that are easily transported and handled.

CHLORINE GAS.

Until within a few years chlorine has been manufactured commercially by the Weldon or some similar process. In the Weldon process hydrochloric acid is made to react with a complex mixture of manganese hydroxide and lime—"Weldon mud"—the reaction being essentially

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2,$$

though in reality it is much more complex. Recently, however, electrolytic processes have been developed, by which the cost of manufacture has been materially reduced, particularly where cheap water power is available. Chlorine prepared by the mixing of common salt, an acid, and a suitable oxidizing agent was used in England as early as 1800 by Cruikshank, who recommended manganese dioxide and potassium bichromate as oxidizing agents. The objections to the use of gaseous chlorine are chiefly the cost of transportation, the difficulty and danger of handling the gas, and the difficulty of measuring accurately the amount of gas added to the effluent. Furthermore, in disinfection free chlorine is not so efficient as the hypochlorite.

Available chlorine, a term frequently used in the discussion of chlorine disinfection methods, is determined by titrating a solution with arsenious acid, or with some other reducing agent, and it represents in reality the oxidizing power of the substance expressed in terms of chlorine. For example, hypochlorous acid in the presence of a reducing agent is decomposed according to the following equation:

$$HClO = HCl + O.$$

The oxidizing power of this acid, or the available chlorine, is, therefore, two hydrogen equivalents per molecule, which is twice its total chlorine content, a fact that makes the term available chlorine a misnomer, but it has come into general use in the chlorine industries and it is a convenient expression. In this article it signifies oxidizing power, determined against arsenious acid, and expressed in terms of chlorine.

HYPOCHLORITES.

Use in disinfection.—Chlorine is handled commercially in the form of bleaching powder, or chloride of lime—an impure product composed largely of calcium hypochlorite. Bleaching powder or "bleach" containing from 35 per cent to 40 per cent of available chlorine can be obtained in the market. The hypochlorite dissolves in water, leaving a residue composed chiefly of calcium hydrate and calcium carbonate. Hypochlorites in general are made by adding chlorine to caustic alkalies. Bleaching powder is made by passing dry chlorine gas over freshly-slaked lime. It is manufactured in this country in large amounts, the chlorine being obtained by the electrolysis of salt. Abroad the chlorine is made by the older methods, and much foreign bleach is sold in this country in competition with the electrolytic product. "Eau de Javelle" and "Labarraque's solution" are solutions of sodium hypochlorite. "Chloros," a commercial preparation of sodium hypochlorite, contains 10 per cent by weight of available chlorine.

Hypochlorites have long been recognized as powerful and efficient disinfectants. The sodium and potassium compounds have not been generally used on a large scale because of their relatively high cost and the difficulty of preparing and keeping them in the dry state, but calcium hypochlorite has been extensively employed. The first Royal Sewage Commission of Great Britain used it in deodorizing London sewage in 1854.[a] The committee of 1885 of the American Public Health Association found it to be the best disinfectant available, cost and efficiency considered. It was used by Dibdin [b] in 1884 to deodorize the sewage of London, but it was not successful for that purpose and was later abandoned in favor of sodium permanganate. Its action on specific bacteria was studied by Nissen [c] in 1890. The use of bleaching powder as a sewage disinfectant has been more extensively studied in Germany than elsewhere. At the Hygienic Institute of Hamburg investigations have been made by Proskauer and Elsner, Dunbar and Zirn, Dunbar and Korn, Schumacher, and Schwarz. At the Royal Testing Station in Berlin, Kranepuhl and O. Kurpjuweit have each reported investigations.

Hamburg experiments.—Proskauer and Elsner [d] experimented at Hamburg with sewage which had been clarified by the Rothe-Degener system. They obtained satisfactory disinfection with chloride of lime, using concentrations of chlorine ranging from 2.7 to 4.0 parts per million, and ten minutes exposure sufficed practically to eliminate *B. coli.* Dunbar and Zirn [d] treated crude sewage and, in common with later workers, they imposed much more exacting standards of disinfection and used much greater concentrations of chlorine. After having employed cholera germs as test organisms, they concluded that the satisfactory disinfection of crude Hamburg sewage would require 25 parts per million of available chlorine and an exposure of two hours. Dunbar and Korn [e] studied the disinfection of crude sewage with special reference to its subsequent purification on biological filters. Schumacher[f] investigated the problem of disinfecting hospital sewages that had not received any previous treatment. In a

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[a] Second Rept. Royal Sewage Commission, London, 1861.

[b] Dibdin, W. J., Jour. Assoc. Eng. Soc., vol. 40, 1908, p. 310.

[c] Zeit. Hyg., vol. 8, 1890, p. 62.

[d] Vierteljahrsschr. ger. Med., vol. 16, 1898, Suppl. Heft.

[e] Ges. Ing., vol. 27, 1904.

[f] Idem, 1905.

preliminary set of bottle experiments he obtained the following results with the sewages of three hospitals.

TABLE 3.—*Disinfection of three crude hospital sewages with chloride of lime.*

[Schumacher.]

Concentration of chloride of lime.	Hours of contact.	Bacteria per cubic centimeter.		
		Initial content: 23,000,000.	Initial content: 37,000,000.	Initial content: 21,000,000.
		After treatment.	After treatment.	After treatment.
1:7,000	2	540	200	8,400
	4	140	260	100
	6	200	100	20
	24	160	20	60
1:5,000	2	60	60	100
	4	160	40	800
	6	120	....	600
	24	30	....	....
1:2,000	2	80	420	40
	4	20	....	60
	6	20	20	20
1:1,000	2	60	20	80
	4	120	40	180
	6	40	40	....

The amount of available chlorine in the chloride of lime used in these experiments is not stated, but it was probably not far from 30 per cent. On that assumption the concentration of available chlorine in the four sets of tests would be 43, 60, 150, and 300 parts per million, respectively. The high initial numbers indicate a very strong sewage. It is also worthy of note that the reduction in the number of bacteria with only 43 parts of chlorine is much greater than would be demanded in ordinary practice. Disinfection on a large scale was also conducted by the same investigator at two hospitals. After a storage period of two hours samples of one liter each were tested for *B. coli.* With a concentration of 1:2,000, or about 150 parts per million of available chlorine, *B. coli* was isolated from a liter of water in only 6 samples out of 43, not being found in 88 per cent of the samples tested. With chloride of lime in the proportion of 1:5,000, or about 60 parts per million of available chlorine, *B. coli* was destroyed in 62 per cent of the samples in two hours and in 64 per cent of the samples in four hours. Schwarz[a] called attention to the fact that excessive amounts of disinfectant are necessary on account of the large floating particles, a point previously commented on by Schumacher. Schwarz proposed, therefore, that all sewage should be carefully screened before disinfection in order to remove particles exceeding three millimeters in diameter. The screening of hospital sewage should be even more complete, removing particles exceeding one millimeter in diameter.

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[a] Ges. Ing., vol. 29, 1906, p. 773.

During experiments at the Eppendorfer purification works, a sewage flow of about 60,000 United States gallons a day was available, and a tank holding about four hours' flow was used. As information was especially desired regarding the effect of the treatment on the cholera vibrio, an emulsion of another vibrio (Leuchtvibrionen) was added to the sewage at a regular rate before treatment, after it had been determined that this test organism would not only pass through the tank but would persist for days in the filters. Table 4 summarizes the results.

TABLE 4.—*Disinfection of the crude screened sewage of Eppendorfer, Germany, with chloride of lime.*

[Schwarz.]

Concentration of chloride of lime.[a]	Tests for vibrio in 1 cubic centimeter amounts.		Test for B. coli in 1 cubic centimeter amounts.		Final number of bacteria per cubic centimeter.[b]
	Total number of tests.	Number of positive tests.	Total number of tests.	Number of positive tests.	
1:2,000			17	0	15
1:5,000	51	0	51	1	23
1:10,000	28	0	7	0	36
1:20,000	15	0	6	0	72
1:30,000	10	0			3,620
1:40,000	8	4			59,000
Control					950,000

[a] 1:10,000 is about 30 parts per million of available chlorine, assuming that the chloride of lime contained 30 per cent of available chlorine.

[b] Initial number of bacteria per cubic centimeter, 1,350,000.

It was noted that a concentration of chloride of lime of 1: 2,000 materially affected the subsequent treatment of the disinfected sewage in trickling filters. Oxygen consumed and ammonia in the effluent were higher and nitrates lower than normal. An interesting fact noted was the production of chlorates in the filter, over 10 parts per million being recorded at one time. Schwarz concluded that sewage can be satisfactorily disinfected with chloride of lime after having been carefully passed through one millimeter mesh screens. One part in 5,000 (60 parts per million of available chlorine) was considered necessary for the destruction of typhoid germs and from one part in 7,000 to one part in 10,000 (30 to 40 parts of available chlorine) for cholera vibrio. The disinfected sewage can be subsequently purified without previous neutralization of the disinfectant.

Berlin experiments.—At the royal testing station in Berlin the subject of sewage disinfection has been studied by Kranepuhl[a] and by Kurpjuweit.[b] Kranepuhl undertook to determine the concentration of chloride of lime and the time of contact necessary to destroy the colon bacilli in crude Berlin sewage. These bacilli numbered

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[a] Mitteilungen aus der Könighlichen Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 9, 1907, p. 149.

[b] Idem, p. 162.

about 100,000 per cubic centimeter. They were considered an index of the pathogenicity of the sewage, because they are more numerous and more resistant than the pathogenic forms. The bleaching powder employed contained available chlorine ranging from 25 to 35 per cent. One liter samples of sewage were treated with the desired amounts of chloride of lime, and at the expiration of the specified time the remaining available chlorine was determined and was then neutralized with sterile sodium thiosulphate. Nutrient broth was then added to the entire liter sample, after which the sample was incubated. *B. coli* was sought in the incubated sample by the usual means, and confirmatory tests for it were made.

Kranepuhl's results are summarized in Table 5, in which positive tests mean that *B. coli* was found in 1 liter.

TABLE 5.—*Disinfection of crude Berlin sewage with chloride of lime.*

[Kranepuhl.]

Available chlorine (in parts per million.)	Time of exposure.	B. coli in liter samples.		
		Number of samples tested.	Number of positive tests.	Per cent of positive tests.
	Hours.			
50	2	20	11	55
50	4	9	2	22
60	2	17	6	35
60	4	6	3	50
150	2	19	4	21
150	4	10	1	10
300	2	16	1	6
300	4	7	0	0

Kurpjuweit[a] studied the penetration of solid particles by the disinfectant. He made test cubes of gelatine having a volume of about 10 cubic centimeters, which he immersed in solutions of chloride of lime for definite times, then removed and melted in warm water, after which he determined the available chlorine. He found the amount of available chlorine to be a regular function of the time of exposure and of the concentration of the solution. The most striking fact noted was the small quantity of chlorine actually absorbed. For instance, a cube that had been immersed for ninety hours gave a mean concentration of chlorine within its own volume equal to but 1 per cent of the concentration of the solution. There was also shown to be a chemical combination between the chlorine and the gelatine. In order to determine whether such chlorine was active in disinfection before it became combined, similar gelatine cubes, inoculated with *B. coli* before setting, were immersed for two hours in solutions containing from 60 to 3,000 parts per million of available chlorine. The results in Table 6 were obtained.

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[a] Loc. cit.

Table 6.—*Destruction by chloride of lime of B. coli embedded in gelatine.*

[Kurpjuweit.]

Concentration of solution (average available chlorine in parts per million).	Number of B. coli remaining in 10 cubic centimeters after 2 hours.
0 (control)	91,500
60	55,400
150	43,500
300	48,100
300	6,600

The value of these results in practical work is problematic for several reasons. The cubes employed are much larger than the particles that should be in any sewage to be disinfected, and the character of the material is still more significant, because cubes of solid gelatine do not represent in any way the porous, semisoluble masses that occur in sewage. The question of penetration is an important one, and there can be no doubt that the practical efficiency of disinfection processes is limited by the ability of the disinfectant to penetrate small, solid particles that may be in the sewage. This point has been illustrated in a practical manner by Kurpjuweit's experiments. Four samples of crude sewage were screened through sieves having openings 2, 5, 7, and 10 millimeters in diameter, respectively. Four portions of each of the filtrates thus obtained were then treated with chloride of lime, so proportioned that the available chlorine was 150, 300, 600, and 3,000 parts per million, respectively. In the sewage that was screened through a 2-millimeter mesh, 150 parts per million of available chlorine destroyed all the *B. coli* in four separate liter samples, while the same concentration of chlorine destroyed the *B. coli* in only 5 out of 8 liter samples screened through the 10-millimeter mesh. Indeed, 3,000 parts of available chlorine were required to remove completely the *B. coli* in the samples screened through the 10-millimeter mesh.

It should be noted that the investigators at Hamburg and at Berlin dealt wholly with crude sewage. Even when purification plants are in operation the disinfection is invariably applied first. No good reason for this procedure is obvious, unless it is that preliminary sedimentation tanks are available and supplementary tanks are not. In Germany the method of operation is possibly justified by the fact that the processes are being studied in order that they may be adopted for temporary use during epidemics, and it is not proposed to practice disinfection regularly. The expense of treating crude sewage, however, is at least twice that of treating a well-purified filter effluent. The very high standards that have been established for this work are also of interest. It is proposed so to treat a sewage containing over 100,000 *B. coli* per cubic centimeter that the number of that kind of bacillus will be reduced to less than one in a liter. The result can hardly be expressed in per cent purification, and it is proper to inquire why such severe standards are employed. If the number of colon bacilli were reduced even to one per cubic centimeter, it would mean a reduction of 99.999 per cent. It may safely be inferred that the number of typhoid and cholera germs would be reduced in about the same ratio, and furthermore that the number of typhoid and cholera cases due to the discharge of this sewage would be similarly decreased. In other words, if such disinfection were generally adopted, 99,999 cases of disease out of every 100,000, which are due, directly or indirectly, to sewage pollution, would be eliminated. Such reduction would seem to be very satisfactory, and yet it is proposed to improve this a thousand fold by insisting on an elimination of the colon bacilli from 1-liter samples, thus making the cost so great that it practically prohibits the use of the process, except for short periods during serious epidemics. It is well worth considering whether a continuous removal of 99 per cent of the disease germs is not a better safeguard of the public health than an occasional complete removal during epidemics.

Experiments at Bengal, India.—The government of Bengal,[a] in 1904, appointed a commission to report on the pollution of Hooghly River by the effluents of septic tanks. Though the commission decided that the physical and chemical pollution of the river by the effluents was improbable, as sufficient dilution took place at all seasons to prevent any nuisance, bacterial purification of the effluents was deemed advisable. Experimental sand filters and copper sulphate disinfection satisfactorily removed the germs, but substitution of chloride of lime for the copper salt accomplished the same result at much less expense.

A septic tank installed near Calcutta was connected with a public latrine serving about 2,000 persons. From 400 gallons to 2,500 gallons of septic-tank effluent were daily treated with various amounts of chloride of lime, the available chlorine in which ranged from 20 to 60 parts per million. The numbers of bacteria initially present were not determined, but the final numbers are sufficiently low to indicate a satisfactory treatment. Furthermore, it was shown that increasing the concentration of the chlorine beyond a certain limit has very little effect on the residual bacteria. The results of this work are summarized in Table 7.

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[a] Indian government resolution on the working of septic tanks. Calcutta, January 6, 1906.

TABLE 7.—*Disinfection of septic sewage by chloride of lime at Bengal, India.*

Available chlorine (in parts per million).	Number of tests.	Number of samples.	Bacteria remaining (average number per cubic centimeter).
20	9	31	33
30	7	24	10
40	8	28	48
60	7	25	52

Experiments in Ohio.—In 1907 the Ohio State Board of Health studied the disinfection of sewage effluents in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. The results, reported by Kellerman, Pratt, and Kimberly,[a] related in part to the use of chloride of lime. The average results of four series of tests made with this disinfectant are summarized in Table 8.

TABLE 8.—*Disinfection of effluents with chloride of lime at Lancaster and at Marion, Ohio.*

[Kellerman, Pratt, and Kimberly.]

Series.	Available chlorine (in parts per million).	Number of bacteria per cubic centimeter at 20° C.		Number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter at 37° C.	
		Initial.	Final.	Initial.	Final.	Initial.	Final.
A	4.0	130,000	140	14,000	49	840	0
B	2.8	60,000	1,600	12,000	120	3,000	0
C	4.1	225,000	1,600	120,000	390	16,000	1
D	6.0	2,000,000	700,000	900,000	230,000	70,000	24,000

Each series represents a three-day test, during which 18 samples were examined in duplicate. Series A was made on the effluent of a sand filter at the Boys' Industrial School, Lancaster, and Series B, C, and D on the sand-filter effluent, contact-filter effluent, and septic-tank effluent, respectively, at Marion, Ohio. A subsequent study of the possibilities of treating the septic tank effluent at Marion led the authors to conclude that satisfactory disinfection could be accomplished by the use of sufficient bleaching powder to give 25 parts per million of available chlorine.

ELECTROLYTIC CHLORINE PROCESSES.

Electrolytic manufacture of chlorine.—When an electric current under a tension of not less than 2.5 volts is passed through a solution of common salt or of calcium or magnesium chloride, chlorine gas appears

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[a] Kellerman, K. F., Pratt, R. W., and Kimberly, A. E., The disinfection of sewage effluents for the protection of public water supplies: Bull. 115, Bur. Plant Industry, U. S. Dept. Agr., 1907.

at one electrode and sodium hydroxide or the corresponding alkali at the other. In the electrolytic manufacture of chlorine the products of the dissociation are kept apart and are removed from the cell as quickly as possible, for if they are allowed to come together again they immediately unite and form a hypochlorite. This method of manufacturing hypochlorites has been employed in many of the so-called "electrolytic disinfection processes."

The Webster process.—One of the earliest electrolytic treatments was devised by Webster over twenty years ago, when, in 1889, he installed an experimental electrolytic plant at Crossness, England, to treat London sewage.[a] In his process crude sewage flowed between iron electrodes placed in long troughs, and an electric current was passed from one electrode to the other at a tension of only two volts and a current density of 0.9 ampere per square foot of electrode. It was estimated that the treatment of 1,000,000 gallons of crude sewage required the consumption of 240 pounds of iron and 450 kilowatt hours of electricity. Sedimentation followed the electrical treatment, and a large amount of material was removed. In fact the process was virtually one of chemical precipitation, the iron dissolved from the electrode being first converted into hypochlorite, or other salt, and then being decomposed by the alkali present and precipitated. The solution of iron at the positive pole allowed the electrolytic reaction to proceed at a lower voltage than that required to liberate free chlorine. The results shown in Table 9 are the averages of 20 analyses, and they indicate the degree of purification obtained by the Webster process.

TABLE 9.—*Analyses of London sewage before and after treatment by the Webster process.*

	Parts per million.	
	Initial.	Final.
Suspended solids	333.5	15.6
Nitrogen as free ammonia	43.4	32.2
Albuminoid ammonia	5.0	2.0
Oxygen consumed	12.4	5.2

Though the process was originally conducted as a chemical precipitation, credit is due Webster for first pointing out the disinfecting value of the hypochlorites that are formed. T. M. Drown,[b] commenting on the process, observed that the American Public Health Association recognized the value of hypochlorites as early as 1888, and that their electrolytic manufacture was nothing new. Nevertheless its application to sewage was new and gave promise of success.

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[a] The Engineer, London, vol. 67, 1889, p. 261; also Eng. News, vol. 21, 1889, p. 338; vol. 22, 1889, p. 388.

[b] Jour. New England Waterworks Assoc., vol. 8, 1894, p. 135; also Eng. News, vol. 31, 1894, p. 236.

In a later paper before the British Medical Association[a] Webster called attention to the possibilities of electrolyzing sea water and thus laid the foundation for the many later processes that are based on that principle. A plant was later installed at Bradford, England, and in 1890 Doctor McLintock stated that 70 per cent of the putrescible organic matter of the sewage had been removed.[b]

Fermi,[c] after having investigated the process at the hygienic institute at Munich, concluded that the process is one of chemical precipitation and that it is more expensive than the lime process, and similar conclusions were reached by König and Remele.[d]

The Woolf process—Electrozone.—Woolf's process differed from Webster's in that strong brine was electrolyzed, and the resultant chlorine and caustic soda were allowed to recombine to form sodium hypochlorite. The hypochlorite solution was then added to the sewage or water to be treated. In the spring of 1893 a plant of this kind was installed under the direction of the health department of New York City for treating the sewage of about 31 dwellings at Brewster, N. Y.,[e] a village situated on a small stream, the waters of which discharge into Croton Lake. The experiment was considered so successful that the health department installed a similar plant at the same place to discharge hypochlorite solution into Tonnetta Creek.[f] Sixteen hundred pounds of salt per million gallons of sewage were used, and the plant required an electric current of 700 amperes at 5 volts tension. This seems to have been the first plant established for the specific purpose of destroying bacteria; before that time the removal of organic matter had been the aim. An electrozone plant installed at Maidenhead, England, in 1897, was examined by Rideal, Robinson, and Kanthack in 1898. The bactericidal action was marked and the effluent was found to contain but few bacteria; this plant was not, however, continued[g] in operation. At Havana, Cuba, the Woolf process was employed for preparing a disinfectant solution to be used for treating the streets and the harbor.

The Hermite process.—The Hermite system differs from the Woolf system only in minor details. In reports on the process great stress is laid on the presence of magnesium hypochlorite in the electrolyzed solution, and there is much evidence that magnesium hypochlorite, owing probably to its lesser stability, is a more active agent than other hypochlorites. In later years this same fact has been observed,

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[a] Eng. News, vol. 22, 1889, p. 388.

[b] Brit. Med. Jour., vol. 2, 1890, p. 498.

[c] Arch. f. Hyg., vol. 13, 1891, p. 207.

[d] Arch. f. Hyg., vol. 28, 1897, p. 185.

[e] Eng. News, vol. 30, 1893, p. 41.

[f] Eng. Record, vol. 29, 1894, p. 110; Elec. Eng., vol. 18, 1894, p. 101.

[g] Rideal, S., Sewage and its purification, 3d ed., New York, 1906, p. 185.

and it has been the basis of fanciful claims for patented processes, whose owners have invoked hypothetical oxides of chlorine to explain the results. A commission appointed by the London Lancet to investigate the Hermite process found that the solution obtained was similar to ordinary hypochlorite[a] in its chemical properties. A plant installed at Worthing, England, was investigated in 1894 by Kelly,[b] who reported that the hypochlorite solution contained from 0.22 to 0.75 gram per liter of available chlorine. The claim made for this solution—that mixed with equal parts of sewage it would instantly kill all germs—was not substantiated. A plant employing the Hermite process, established at Havre, France, in 1893, was investigated by a commission appointed by the imperial board of health of Germany and by one sent from Paris by the council of hygiene, and both bodies reported adversely. Other Hermite plants were installed at various places, but were finally abandoned. At Poplar, England, the Hermite solution is prepared on a large scale, and it is used for general disinfecting purposes as well as for street watering.

The oxychloride process.—The oxychloride process differs from the Hermite and Woolf processes only in matters of detail in the electrolytic cell. Greater efficiency than the older processes in the production of hypochlorites is claimed for it. At Guilford, England, Rideal made a test of the effect of oxychloride treatment on raw and septic sewages and on effluents of primary, secondary, and tertiary contact beds. The summary of his results given in Table 10 shows what was accomplished. The results, especially in respect to the removal of *B. coli*, are all that can be desired.

TABLE 10.—*Summary of Rideal's experiments on the use of oxychloride at Guilford, England.*

Source of sample.	Available chlorine parts per million.	Time of contact.	Number of organisms per cubic centimeter.					
			Total.		B. coli.		B. enteritidis.	
			Initial.	Final.	Initial.	Final less than—	Initial.	Final less than—
Sewage	30	4.3 hours	23,000,000	50,000	1,000,000	1.0	1,000	10.0
	50	do	23,000,000	20	1,000,000	.2	1,000	.2
	70	do	23,000,000	10	1,000,000	.2	1,000	.2
Septic effluent	25–44	1 to 4 hours.	2,500,000–4,500,000	20–600	100,000–1,000,000	1.0–.2	10–1,000	1.0–.2
Effluent from first contact bed.	20	40 minutes	......	......	100,000	.2	......	......
	20	2 hours	......	......	......	......	20–100	.2
Effluent from second contact bed	10.6	......	1,000,000–2,000,000	40	1,000,000	.2	10–1,000	.2
Effluent from third contact bed.	2.5	1 hour	......	......	1,000–10,000	.2	......	......
	2.5	4.5 hours	......	......	......	......	10–100	1.0
	.5	0.5 hour	......	......	1,000–10,000	.2	......	......
	.5	4.5 hours	......	......	......	......	10–100	0.2

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[a] Lancet, vol. 1, 1894, p. 1321.

[b] Public Health, vol. 6, 1894, p. 261.

Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group—aerobic spore-forming bacteria which are probably beneficial in the further oxidation of the organic matter. Absolute sterilization required very high concentration of chlorine.

COPPER AND ITS COMPOUNDS.

Moore and Kellerman, in 1904, suggested that copper sulphate be used in water sterilization.[a] Since that time a great deal of experimental work has been done, mainly in connection with water. The more important experiments, with sewage will be outlined.

Johnson and Copeland[b] at Columbus, Ohio, in 1904, in their work with trickling filter effluents, obtained the results given in Table 11.

Table 11.—*Disinfection of trickling filter effluents with copper sulphate at Columbus, Ohio.*

[Johnson and Copeland.]

	Copper sulphate in parts per million.	Reduction in bacteria (per cent).	
		In 3 hours.	In 24 hours.
First series, average of 3 sets	5	90.0	99.9
	10	98.0	99.95
	20	98.5	99.96
Second series, average of 3 sets	10	40.0	99.7
	20	60.0	99.9
	40	88.0	99.95

They found the action of copper sulphate to be most rapid during the first hour. They estimate the cost for chemicals alone at $5 per million gallons of effluent treated with 10 parts per million of copper sulphate, and $10 if treated with 20 parts per million—an expense which they consider prohibitive.

The use of copper sulphate as a disinfectant was more thoroughly investigated by Johnson at Columbus in 1905.[c] Experiments were made with crude sewage, and with effluents from trickling, contact, and sand filters. The effect of temperature, of organic matter, and of alkalinity on the efficiency of the process were determined and special studies were also made to determine the effect of the treatment on colon and typhoid organisms. The principal results with the various sewages treated are summarized in Table 12.

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[a] U. S. Dept. Agr., Bureau of Plant Industry, Bull. 64, 1904.

[b] Jour. Infect. Diseases, Suppl. No. 1, 1905, p. 327; also Reports and papers, Am. Pub. Health Assoc. vol. 30, pt. 2, p. 327.

[c] Report on sewage purification at Columbus, Ohio, 1905, p. 471; also Jour. New England Waterworks Assoc., 1905, p. 474.

TABLE 12.—*Results of disinfection of sewage and effluents with copper sulphate at Columbus, Ohio; total number of bacteria remaining after contact periods of one hour and of three hours.*[a]

[Johnson.]

Copper sulphate (in parts per million.)	Series A.	Series B.		Series C.		Series D.	
	1 hour.	1 hour.	3 hours.	1 hour.	3 hours.	1 hour.	3 hours.
1,000	3,000	1,000	240	430	60	2,100	280
200	....	5,000	600	1,100	130	6,000	1,400
100	9,000	6,000	500	2,100	230	5,500	1,800
40	....	3,400	700	1,200	230	6,500	1,300
20	14,000	11,000	1,900	3,500	600	13,000	2,600
10	....	21,000	4,500	7,500	1,200	20,000	5,000

		Bacteria per cc.
[a] Series A.	Crude sewage; initial number	1,200,000
B.	Effluent of sprinkling filter	1,000,000
C.	Effluent of contact filter	400,000
D.	Effluent of sand filter	280,000

Each series is the average of from three to five sets of tests.

Longer periods of contact up to twenty-four hours gave results of no additional significance, except that when the lower concentrations of copper were used the number of bacteria showed a decided increase after about the third hour, an indication that the copper was removed from solution, probably by combination either with the organic matter or with carbonic acid. Subsequent increase in number of bacteria is a phenomenon of frequent occurrence in disinfection work. It is in fact neither possible nor desirable to prevent perpetually the feeding of bacteria on the organic matter of the disinfected effluents. The significant fact in Johnson's tests is that the bacteria originally present were practically eliminated, and it may safely be assumed that under conditions existing in a stream there would be no multiplication of the typhoid or other pathogenic bacteria.

Two important facts were brought out in this study. The disinfection obtained with 100 parts per million of copper sulphate is, for practical purposes, but little better than that obtained with 10 parts, and results obtained in a one-hour contact are practically as good as those obtained in a three-hour contact. Johnson's work was done at summer temperature, and in order to determine the effect of temperature on the germicidal action parallel experiments were conducted at 5° and at 20° C. It was found in general that a result which could be obtained at the higher temperature in thirty minutes would be attained at the lower temperature in about three hours. This is a point that has usually been overlooked, and it is of special significance in practical operation, as effluents in the northern latitudes would have a temperature of about 5° C. during much of the year. It is interesting to note that temperature has little effect on the germicidal efficiency of hypochlorites.

The combined effect of organic matter and alkalinity was determined by treating the undiluted effluent and the same effluent after being diluted 1 to 1 and 1 to 2 with tap water. The effect was decidedly noticeable in the weaker concentrations of copper sulphate, and much less so where the concentrations of copper were excessive. The results with 10 parts of copper sulphate per million are summarized in Table 13.

TABLE 13.—*Effect of organic matter and of alkalinity on the germicidal properties of copper sulphate: per cent removal of bacteria at end of one hour's contact with 10 parts per million of copper sulphate.*

[Johnson.]

Source of sample.	Dilution.		
	0	1:1	1:2
Crude sewage	96.1	97.5	98.5
Trickling filter effluent	97.3	99.0	99.1
Sand filter effluent	70	86	91

The efficiency of copper sulphate as a disinfectant was investigated in 1906 at the Sanitary Research Laboratory of the Massachusetts Institute of Technology by treating the effluent from an 8-foot trickling filter. Table 14 gives the average results divided into two periods to show the effect of temperature of the effluent. At the conclusion of the tests a composite sample of the sediment drawn from the sedimentation tank during the experiment was analyzed. The copper contained in the sediment accounted very closely for the total amount of copper added, a fact that makes it apparent that little copper left the tank in soluble form.

TABLE 14.—*Disinfection of trickling filter effluent with copper sulphate at Boston, Mass.; average results.*

Period.	Copper sulphate (in parts per million).	Temperature.	Number of bacteria per cubic centimeter.			Number of B. coli[a] per cubic centimeter.		
			Initial.	Final.	Per cent removed.	Initial.	Final.	Per cent removed.
1906.		°F.						
October 13–31	4	56	230,000	14,000	94.0	44,000	640	98.5
November 3–19	4	46	250,000	51,000	80.0	48,000	770	98.4
November 21–December 10	8	43	240,000	5,000	97.9	32,000	390	98.8

[a] Jackson's bile media used.

The work of Kellerman, Pratt, and Kimberly in Ohio during the winter of 1906–7 consisted mainly of experiments with copper sulphate as a disinfectant. Their investigations, probably the most comprehensive ever made with copper sulphate, were conducted under actual working conditions and with several kinds of effluent. The chemical composition of the water, particularly in regard to its hardening constituents, was found to exert an important influence on the results. Their original paper[a] on the subject contains complete chemical analyses of the effluents treated. Table 15, containing a brief summary of average results calculated from the original tables, shows in a general way what was accomplished. The authors concluded that copper sulphate is not so efficient as chlorine compounds, is more seriously affected by carbonates, and is much more expensive.

Table 15.—*Disinfection of effluents with copper sulphate in Ohio.*

[Kellerman, Pratt, and Kimberly.]

Series.	Copper sulphate (in parts per million.)	Number of bacteria per cubic centimeter at 20° C.		Number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter.	
		Initial.	Final.	Initial.	Final.	Initial.	Final.
A	5	6,000,000	1,200,000	140,000	120,000	6,000	600
	6.7	250,000	70,000	19,000	10,000	6,000	900
	10	60,000	16,000	47,000	10,000	2,600	1,000
	13	65,000	23,000	37,000	5,500	4,600	600
	20	120,000	20,000	8,000	11,000	1,600	110
	29	60,000	3,900	24,000	6,000	1,200	10
	40	160,000	8,500	75,000	4,700	5,500	110
	67	200,000	34,000	81,000	14,000	7,000	700
B	7.3	110,000	23,000	12,000	1,800	600	48
	14	75,000	9,500	16,000	600	75	0
	22	55,000	7,000	5,500	200	75	0
C	6.5	390,000	110,000	170,000	41,000	8,000	3,000
	15	230,000	65,000	42,000	16,000	5,000	2,200
	40	29,000	6,000	30,000	8,500	5,500	750
	116	84,000	7,000	28,000	2,000	5,000	560

A. Effluent of contact filter at Westerville, Ohio.
B. Effluent of sand filter at Lancaster, Ohio.
C. Effluent of sand filter at Marion, Ohio.

MISCELLANEOUS METHODS.

PERMANGANATES.

Potassium permanganate and sodium permanganate have been used for the oxidation of organic matter in streams. At London when the Thames becomes extremely foul during low-water periods, sodium permanganate is added to its waters in order to destroy odors and putrescible material, but the treatment undoubtedly results in partly sterilizing the water. It is claimed that the germicidal action is not sufficiently great to interfere with the normal oxidizing changes in the stream. The use of permanganates has been proposed for rendering effluents of chemical precipitation plants nonputrescible.

"AMINES" PROCESS.

The so-called "amines" process was developed by H. Wollheim in England. It is claimed that trimethylamine treated with lime or other alkali produces a very poisonous substance. Herring brine is

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[a] Kellerman, K. T., Pratt, R. W., and Kimberly, A. E.: The disinfection of sewage effluents for the protection of public water supplies, Bull. 115, Bur. Plant Industry, U. S. Dept. Agr. 1907.

used to supply the amine. A large excess of lime is added and the mixture is used to precipitate crude sewage. Klein made a test of the process at West Horn in 1889, and found that a clear, nonputrescent, sterile effluent could be obtained. Similar results were obtained at Wimbledon,[a] where 768,000 bacteria per cubic centimeter in the sewage were completely removed. The sludge is also nonputrescible. The process does not seem to have been further developed.

SODIUM BENZOATE AND OTHER ORGANIC COMPOUNDS.

Sodium benzoate is supposed to possess powerful germicidal properties, and its use as a disinfectant for sewage was suggested to the writer. It would apparently have the distinct advantage over such other disinfectants as chlorine and copper salts of not combining with organic matter, thus rendering all the disinfectant added available for a long time. Sodium benzoate was applied regularly to a trickling filter effluent at Boston during March and April, 1907. An addition of commercial benzoate at the rate of 0.8 part per million for twenty-six days gave an average reduction of total bacteria from 140,000 to 54,000 per cubic centimeter, or a 62 per cent removal. Doubling the amount of benzoate increased the efficiency somewhat, the average reduction then being from 370,000 to 84,000 per cubic centimeter, or 78 per cent. The cost of benzoate for the treatment is $1 per million gallons for 0.8 part and $2 for twice that quantity. Obviously this substance is not an efficient disinfectant in sewage work.

Other organic substances, such as the phenols and the coal-tar products, were suggested, but in general their high cost eliminates them from consideration. The possibility of after effects must also be considered. There is a certain advantage in the use of a substance which is itself used up in the reaction or which is converted into harmless compounds. On the other hand, the organic disinfectants are extremely powerful and there is always a chance of the discovery of some new compound with the requisite germicidal properties and the low cost that will make it the ideal sewage disinfectant.

SUMMARY OF DISINFECTION METHODS.

Two of the methods of disinfection that have been mentioned appear not to have been sufficiently investigated, namely, disinfection by heat and by organic compounds. The heat method holds a reasonable possibility that sufficient ammonia may be recovered to pay for the necessary heating, but actual trial is essential for convincing proof. A systematic study of organic compounds as disinfectants has yet to be made.

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[a] Interim Rept. Royal Sewage Commission, 1901, p. 304.

Of the disinfectants that have been sufficiently investigated, chlorine compounds and copper salts alone appear to be applicable to the sewage problem. Moreover, a detailed study of results on a cost basis leaves no doubt that the efficiency of chlorine is much greater than that of copper. Even if the prices of these two materials were more nearly equal, many facts favor the use of chlorine. Both reagents unite with organic matter, but chlorine unites by oxidizing the organic matter, thus rendering it less putrescible, while copper precipitates it. The compounds formed by the copper tend to protect the solid particles from further action, and the diffusion of copper ions through such a precipitated copper envelope must necessarily be slow. As no such action occurs with chlorine compounds, the penetration of the chlorine into solid particles must be much more complete. Chlorine in the form of bleaching powder is to some extent a by-product, is very cheap, and will probably become cheaper as the methods of production are improved; on the other hand, copper is a staple, the price of which is likely to increase. Sewages may be found of such chemical composition that treatment with copper will be more effective than that with chlorine, but in general chlorine compounds are to-day by far the most economical and the most efficient disinfectants available in sewage work.

EXPERIMENTAL INVESTIGATIONS.

HISTORY.

In connection with general investigations in sewage disposal, which have been conducted since 1903 at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology, the subject of the chemical disinfection of sewage and sewage effluents has been extensively studied during the past two years. In the spring of 1906 a cooperative arrangement between the United States Geological Survey and the institute made it possible materially to enlarge the scope of the work.

With a view also of gaining increased knowledge of the practical workings of the processes that had been developed at Boston, an arrangement was made with the state sewerage commission of New Jersey, through Boyd McLean, secretary, under which experiments were begun at Red Bank, N. J. The state sewerage commission later continued that work for its own information, retaining the writer in charge, and through the courtesy of the commission the results of the entire work are here presented. During the summer of 1907 the experiments were placed under the immediate charge of F. E. Daniels, to whose faithful efforts their successful completion is in large part due. Mr. Daniels was assisted at Red Bank by H. S. Crawford, and also did much of the work at Boston during 1908.

In December, 1907, the scope of the investigation was still further broadened by a cooperative agreement between the United States Geological Survey and the sewerage commission of Baltimore, of which Brig. Gen. Peter Leary, U. S. Army, retired, is chairman, and Calvin W. Hendrick is chief engineer. Experiments on a somewhat enlarged scale were immediately undertaken at the Walbrook testing station of the Baltimore sewerage commission, and they were continued up to July, 1908, at which date the agreement with the Geological Survey lapsed. The work at Baltimore was under the immediate charge of Ezra B. Whitman, division engineer of the disposal division, to whom the writer is under the greatest obligation for its successful outcome. Intimately associated with that work also and responsible in large measure for the results have been Charles A. Emerson, jr., assistant division engineer, Henry C. McRae, chemist, and Edward G. Birge, bacteriologist. Dr. R. P. Cowles, of Johns Hopkins University, and William T. Carpenter, Leyland Whipple, and Marvin H. Lillis, have also been associated with this work from time to time in connection with special lines of investigation.

Through the courtesy of A. G. Paine, jr., president, and J. R. Crocker, superintendent, of the McDonald Electrolytic Cell Company, of New York, an electrolytic chlorine cell having a capacity of 22 pounds a day of chlorine gas was placed at the disposal of the writer, and it proved to be of great assistance in the work, as a large supply of gaseous chlorine was thus made available for special experiments. The machine was used directly in disinfection and also in the preparation of a series of chlorine compounds that were studied.

BACTERIOLOGICAL METHODS AND EXPRESSION OF RESULTS.

The bacteriological methods employed in the different parts of this work have been kept as nearly uniform as possible in order that the results may be strictly comparable. In general, the methods have been those recommended by the committee on standard methods of water analysis of the American Public Health Association, laboratory section. Since the publication of those methods,[a] a new presumptive test for the colon bacillus has been described by Jackson[b] and it has been used throughout this work. The medium employed in this test consists of ox bile to which lactose has been added. Its accuracy in sewage work has never been carefully studied, but recent studies by Prescott and Winslow[c] have confirmed the earlier statement of Jackson that in water work this presumptive test gives results which are similar to those obtained in complete *B. coli*

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[a] Jour. Infect. Dis. Suppl. 1, Chicago, 1905. Repts. and Papers American Pub. Health Assoc., vol. 30, pt. 2, 1905.

[b] Biological studies by the pupils of William Thompson Sedgwick, p. 292, Boston, 1906.

[c] Elements of water bacteriology, 2d ed., New York, 1908, p. 149.

determinations. It may fairly be assumed, therefore, that the *B. coli* results reported in the present paper represent a group of bacteria, including practically all the *B. coli* actually present, together with certain other bacteria which probably are not more than 10 per cent of the whole number reported. The study of such a group gives valuable information concerning the probable elimination of typhoid and other pathogenic bacteria, while the additional information to be obtained from a complete determination of the *B. coli* actually present is not deemed sufficient to warrant the additional labor involved. At Boston and at Baltimore counts of the bacteria on gelatin at 20° C. and on litmus lactose agar at 37° C. and counts of the acid-forming bacteria at 37° C. were recorded. The latter group includes the *B. coli,* and some bacteriologists believe that the number of acid-forming bacteria is a more accurate indication of the numbers of colon bacilli than the presumptive tests. It is indisputable, however, that the group of acid-forming bacteria is large and that in sewage work at least it bears only a general relationship to *B. coli.* An additional group, the bacteria that liquefy gelatin, is also included in the Boston results, though the additional information afforded by including this group is slight. Inasmuch as adequate facilities for complete bacteriological work were not available at Red Bank, the total count at 20° C. and the presumptive *B. coli* tests alone were made. Examinations of the trickling filter effluent before and after treatment have been made at Boston on five or six days in each week. At Red Bank and at Baltimore two samples were tested each working day for *B. coli* and three samples were plated for the bacterial counts.

Considerable thought has been given to the manner of expressing results. It would obviously be inadvisable to attempt to tabulate the results of all examinations made, because such tables would be too unwieldy for general use. On the other hand, the use of averages, especially if they cover long periods, is open to the serious objection that a few bad results are easily covered up in general averages, and it is particularly necessary, in a process of this kind, to show that the results are not only satisfactory in general, but that they are fairly uniform. To cite a familiar illustration, a poor marksman's shots might be placed symmetrically about the center of the target and in that sense their average position might be as near the bull's-eye as the average position of better-placed shots. The actual deviations from the average position would indicate the character of the shooting. Similarly, in disinfection two series of tests might give the same average, even if one series were composed of fairly uniform results and the other series of very erratic ones. In other words, the deviations from the average are fully as significant as the average figure itself. Accordingly, the routine work is reported in the form of weekly averages. The total bacterial counts are accompanied by a statement showing the variations of the individual results and the variations of the individual bacterial removals from the average bacterial removal. In this way the record of what was actually accomplished is stated in the most compact form.

A new method of recording *B. coli* results is also employed. The procedures used in the determination of this organism do not permit a quantitative count of the number really present, but show merely the presence or the absence of the bacillus. Quantitative results are obtained in a rough way by applying the test to various dilutions of the sample. For instance, in a disinfected effluent the test is applied on 0.1, 0.01, and 0.001 cubic centimeter, respectively, and the highest dilution giving a positive test is recorded. Hitherto a bare statement of the results is all that has been attempted in the way of giving quantitative significance to this test. But it has been shown [a] that where as many as fifty or one hundred results of that character from the same source are available, the probability law of distribution may be applied in order to estimate the average number of organisms present. The most probable value for the number of *B. coli* present in each sample is indicated by the reciprocal of the highest dilution giving a positive test, and while that figure may be far from the correct one for any one sample, the average of fifty estimates of this character closely approximates the actual value. The case is analogous to the well-known facts in relation to the expectancy of life at any age; an expectancy of life as given in the actuarial tables has but little weight when applied to any one person, but in the average of a large number of persons it approximates the truth. The number of *B. coli* present in a sample has therefore been recorded in this way. Individual results have but little weight and weekly averages must be properly interpreted, but monthly averages are probably very near the average numbers.

INVESTIGATIONS AT BOSTON.

SCOPE AND CHARACTER OF EXPERIMENTS.

Since the beginning of the work at Boston in February, 1906, various phases of the disinfection problem have been under investigation. The following summary of the studies shows their scope and character: (*a*) Preliminary experiments with chloride of lime; (*b*) studies of the comparative efficiencies of chloride of lime, sulphate of copper, and sodium benzoate; (*c*) small-scale experiments to determine the comparative efficiencies of free chlorine, commercial hypochlorites, electrolytic hypochlorites, chlorates and perchlorates, and the hypochlorites of several bases; (*d*) studies of the comparative effect

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[a] Phelps, E. B., A method for calculating the numbers of *B. coli* from the results of dilution tests: Am. Jour. Pub. Hyg., vol. 18, 1908, p. 141.

of hypochlorites on the typhoid and the colon bacilli; (*e*) routine disinfection of 5,000 gallons a day of trickling-filter effluent with chloride of lime; (*f*) disinfection of crude sewage with chloride of lime in 700-gallon tests. The studies on copper sulphate and sodium benzoate have already been discussed (pp. 29–32). The remaining divisions of the work are reviewed in the succeeding pages.

PRELIMINARY EXPERIMENTS WITH CHLORIDE OF LIME.

The results of some preliminary experiments in the spring of 1906 have already been published,[a] but as they have important bearing on the present work, a brief review of them is here presented. The experiments were made with chloride of lime and the effluent of a trickling filter in which Boston sewage was being treated. They consisted of 23 bottle tests in which the available chlorine that was added varied from 0.25 to 100 parts per million, and the time of contact from thirty minutes to twenty-four hours. They were undertaken with the object of establishing practical working limits for available chlorine and contact period for future experiments, and particularly to determine whether the English and Continental practice of adding large, almost prohibitive, amounts of chlorine is justified by the results.

This preliminary study indicated that an effluent similar to the one used can be deprived of 95 per cent to 98 per cent of its total bacteria in two hours by the application of chloride of lime in concentrations having 2 to 5 parts per million of available chlorine. The impracticability of attempting to get much better results was well shown, for complete sterilization was never accomplished, though concentrations of chlorine up to 100 parts per million and storage periods of twenty-four hours were employed. It was found unnecessary, in brief, to use more than 5 parts of chlorine or to treat for over two hours.

It is a well-known fact that, in all processes involving the destruction of bacteria, it is comparatively easy to kill the first 95 per cent of the germs and very difficult to destroy the remaining 5 per cent. This phenomenon of the "resistant minority," as Whipple terms it, is common to all kinds of sterilization, whether it be by heat, cold, light, chemicals, or other means. It is therefore more practical to determine how far disinfection may be carried at a reasonable expenditure than to attempt the ideal complete sterilization. To state a concrete example, it might happen that the pathogenicity of an effluent could be reduced 96 per cent by the expenditure of a certain sum of money, 97 per cent by the expenditure of twice that sum, and 99 per cent by the expenditure of five times that sum. The first reduction might represent a feasible plan, and the last a pro-

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[a] Phelps, E. B., and Carpenter, Wm. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19, 1906, pp. 382–403.

hibitively expensive one. It is plainly more desirable at the outset to determine the relations between the various factors, such as concentration of disinfectant, time of contact, cost, and efficiency, and to establish certain working limits with reference to final costs, than to attempt the ultimate destruction of all germs regardless of the practical limits that necessarily exist. The preliminary experiments were undertaken with the idea of fixing these practical working limits. For the first time in the history of the subject the disinfection of sewage filter effluents and even of crude sewage itself was shown to be practicable and feasible, yielding results commensurate with the cost when compared with the results and costs of other purification processes.

DISINFECTION OF TRICKLING-FILTER EFFLUENT.

The most important work at Boston consisted in the routine disinfection of the combined effluents of two trickling filters. Each filter is 8 feet deep and has a surface area of 50 square feet. One is composed of crushed stone from 1 inch to 1½ inches in mean diameter; the other of stone from 1½ to 2 inches in diameter. The combined effluents, amounting to 5,000 gallons in twenty-four hours, were brought from the underdrains of the outdoor trickling filters to the filter house through a short length of iron pipe. Within the filter house the liquid was conducted by an open trough to the central channel of a sedimentation tank built on the Dortmund plan. It then passed downward nearly to the bottom of this conical tank, entered the main body of the tank, and, rising with constantly decreasing velocity, finally overflowed at the surface. The tank was designed to give a two-hour storage period. The disinfectant solution was made up in a 50-gallon barrel to a strength about one hundred times that required in the final mixture. A small orifice-box working under constant head was connected with the barrel and was designed to deliver exactly 2 gallons an hour. As the flow through the sedimentation tank was a little over 200 gallons per hour, this arrangement gave a final mixture of the desired proportions. These rates and volumes were kept constant throughout, any change in the amount of disinfectant added being brought about by changing the strength of the solution. Readings of a float gauge set in the barrel and daily measurements of the flow of the trickling-filter effluent into the tank served as checks on the accuracy of the dilutions, and together with daily analyses of the strong disinfecting solution, gave data from which the actual amount of disinfectant added during any required period of time could be computed. Observations of the rate of flow of the disinfectant solution into the tank were made at hourly intervals for a period of three hours preceding the taking of samples, and the actual concentration of the disinfectant corresponding to the sample in question was calculated from these observations. The disinfectant solution flowed into the open trough previously mentioned, where it mingled with the effluent. Further opportunity for mixing occurred during the passage down the central channel of the sedimentation tank. Samples for bacterial examination were collected with the usual precautions, before the effluent had reached the wooden trough into which the disinfectant solution was run and also at the final outlet of the sedimentation tank after the combined effluent and disinfectant had been in contact for a period somewhat less than two hours. These samples are described as initial and final, respectively.

The chemical composition of an effluent has an important influence on the germicidal value of most disinfectants, particularly chloride of lime. The chlorine applied is eventually completely consumed by chemical reaction with the organic matter of the effluent, and the germicidal action takes place in the interval of time between the addition of the chlorine and its final exhaustion by chemical reaction. The amount of organic matter present, therefore, practically determines the amount of chlorine that it is necessary to use. For this reason the chemical analyses of the combined effluent are recorded by monthly averages in Table 16. The monthly averages of the analyses of the disinfected and settled effluent are also included to show the chemical character of the effluent after treatment.

TABLE 16.—*Chemical analyses of trickling-filter effluent at Boston before and after disinfection with chloride of lime and sedimentation; monthly averages.*

[Parts per million.]

INITIAL.

Month.	Turbidity.	Suspended solids.		Nitrogen as—					Oxygen consumed.[a]		Dissolved oxygen.
		Total.	Loss on ignition.	Organic.		Free ammonia.	Nitrites.	Nitrates.	Total.	Dissolved.	
				Total.	Dissolved.						
1907.											
November	135	118	78	3.5	1.5	15.0	0.2	2.0	40	32	8.2
December	155	......	......	5.5	3.0	15.5	0.1	1.0	38	33	7.8
1908.											
January	140	92	69	5.0	3.0	15.0	0.3	3.5	45	38	10.0
February	145	177	156	6.0	2.5	14.5	0.1	3.0	44	32	12.5
March	130	180	122	7.5	3.5	15.5	0.2	4.0	48	35	7.8
April	195	313	192	10.5	5.5	14.5	0.4	5.5	64	46	9.4
May	275	436	247	14.0	4.5	14.5	0.9	6.0	70	35	7.4
June	155	174	96	11.5	6.0	7.5	0.8	6.0	49	35	7.1
Average	165	213	137	8.0	4.0	14.0	0.4	4.0	50	36	8.8
FINAL.											
1907.											
November	105	71	53	3.0	1.5	14.5	0.1	2.0	28	27	....
December	145	......	......	4.0	1.5	14.0	0.1	2.0	39	38	....
1908.											
January	115	124	103	3.0	3.0	13.0	0.6	5.0	49	41	....
February	110	259	239	4.5	2.5	13.5	0.3	4.5	42	38	....
March	125	125	82	9.5	3.5	15.0	0.3	3.5	46	42	....
April	105	147	125	5.5	3.5	14.5	0.4	5.0	44	40	....
May	135	92	69	5.0	3.0	15.0	1.0	5.0	44	33	....
June	95	51	43	7.0	4.0	7.5	0.8	6.0	38	33	....
Average	115	124	102	5.0	3.0	13.5	0.5	4.0	41	37	....

[a] Thirty-minute boiling method.

This disinfection experiment was started November 11, 1907, and was continued practically without interruption till June 27, 1908, a period of thirty-three weeks. The value of such continuous experiment is obvious. A certain length of time is always required for for the establishment of uniform working conditions, not only in the personal element but in the tanks themselves. Furthermore, short special experiments receive an unusual and perhaps unfair amount of care and attention, which is not bestowed on work that has become part of the routine, and the natural defects of the processes under practical working conditions are, therefore, not always discovered. The most important value of long-continued tests, however, lies in their being carried out under various seasonal conditions. Fluctuating conditions of temperature and rainfall fundamentally affect the sewage and influence the work of the filter. It is consequently of prime importance to determine the efficiency of any purification process under an extreme range of seasonal conditions. It fortunately happened that the present experiments were continued through an unusually cold winter and through the hottest portions of an exceptionally hot, dry summer.

Table 17 contains the results of the experiments, given in weekly averages, which are the mean of four to six daily results. During the first five weeks the available chlorine added was about six parts per million, but during the remainder of the period this concentration was reduced to between two and four parts without materially affecting the results. The average results for the whole period are indicated in the last line of the table.

TABLE 17.—*Disinfection of trickling-filter effluent with chloride of lime at Boston; weekly averages.*

Week ending—	Temperature.	Available Cl (parts per million).	Number of bacteria per cubic centimeter at 20° C.				Number of bacteria per cubic centimeter at 37° C.				Number of B. coli per cubic centimeter.[a]	
			Total.		Liquefiers.		Total.		Acid formers.			
			Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
1907.												
November 16	45	5.7	1,100,000	1,800	150,000	100	330,000	570	250,000	22	260,000	4
23	46	5.9	800,000	7,500	46,000	600	130,000	500	94,000	250	180,000	20
30	42	6.8	1,000,000	1,800	48,000	43	65,000	600	48,000	110	26,000	1
December 7	36	6.9	600,000	4,500	60,000	90	140,000	140	85,000	44	17,000	0
14	42	5.0	800,000	15,000	60,000	750	140,000	1,500	43,000	850	5,500	33
21	37	3.0	550,000	85,000	27,000	4,500	95,000	6,500	75,000	5,500	4,000	370
28	44	3.1	850,000	20,000	120,000	2,400	210,000	3,400	66,000	1,900	46,000	600
1908.												
January 4	40	2.8	950,000	7,000	70,000	500	90,000	500	70,000	370	65,000	25
11	35	3.2	550,000	17,000	55,000	450	86,000	2,100	50,000	1,900	55,000	750
18	34	2.7	550,000	22,000	47,000	1,300	80,000	1,300	80,000	1,200	8,500	520
25	35	2.7	800,000	35,000	26,000	2,800	110,000	6,000	100,000	5,500	64,000	60
February 1	34	3.3	450,000	75,000	30,000	4,000	70,000	16,000	55,000	11,000	2,500	230
8	33	3.6	800,000	8,000	60,000	400	340,000	2,000	200,000	1,100	10,000	100
15	35	3.4	650,000	43,000	30,000	250	60,000	2,500	50,000	2,000	33,000	280
22	34	3.4	390,000	17,000	24,000	900	74,000	2,600	52,000	2,000	10,000	400
29	34	3.3	550.000	13,000	40,000	100	90,000	3,400	60,000	2,500	33,000	750
March 7	35	3.8	430,000	3,400	30,000	190	140,000	2,300	75,000	1,500	40,000	70
14	38	3.1	500,000	18,000	35,000	700	170,000	5,500	120,000	4,500	25,000	550
21	38	3.0	600,000	7,500	65,000	320	180,000	2,200	140,000	1,800	55,000	360
28	42	2.5	460,000	18,000	36,000	500	140,000	5,700	95,000	4,500	25,000	700
April 4	40	3.2	450,000	8,000	60,000	1,400	140,000	3,000	80,000	2,200	40,000	240
11	42	2.4	2,500,000	37,000	500,000	6,000	160,000	8,500	90,000	4,400	10,000	1,000
18	42	1.7	1,100,000	35,000	220,000	6,000	160,000	4,300	75,000	2,000	70,000	850
25	46	2.7	600,000	100,000	70,000	2,400	150,000	7,500	75,000	2,300	46,000	800
May 2	54	3.4	450,000	2,000	60,000	200	250,000	1,000	55,000	300	55,000	55
9	48	3.1	600,000	23,000	180,000	5,500	210,000	2,200	140,000	900	25,000	400
16	56	3.0	600,000	9,000	85,000	1,200	120,000	1,800	32,000	1,600	40,000	200
23	58	2.6	1,400,000	28,000	220,000	2,400	280,000	11,000	170,000	9,000	85,000	1,000
30	62	2.7	700,000	18,000	130,000	3,800	230,000	6,000	160,000	350	64,000	800
June 6	61	2.8	850,000	34,000	100,000	3,800	190,000	4,600	150,000	3,500	85,000	850
13	68	2.5	550,000	35,000	160,000	1,500	75,000	3,200	55,000	1,500	40,000	200
20	68	2.8	630,000	32,000	120,000	3,600	110,000	4,800	60,000	1,500	8,000	62
27	68	3.0	1,100,000	13,000	120,000	1,300	210,000	5,700	50,000	300	2,800	200
Average	45	3.4	750,000	24,000	95,000	1,800	150,000	3,900	90,000	2,400	47,000	380

[a] Jackson bile media used.

The average efficiencies as measured by the per cent of bacteria removed for the whole period and for certain shorter periods, selected to illustrate the effect of different concentrations of chlorine and of fluctuating conditions of temperature, are shown in Table 18.

TABLE 18.—*Disinfection of trickling-filter effluent at Boston; summary of bacteriological results, averaged by periods, to show the effect of changes in temperature and in the amount of available chlorine.*

Period.	Temperature.	Available chlorine, in parts per million.	Per cent of bacteria removed.				
			Bacteria at 20° C.		Bacteria at 37° C.		
			Total.	Liquefiers.	Total.	Acid formers.	*B. coli.*
	° *F.*						
November 12 to June 27	45	3.4	96.8	98.1	97.4	97.3	99.19
November 12 to December 12	42	6.3	99.57	99.73	99.81	99.91	99.99
January 27 to March 28	36	3.2	95.8	97.7	96.6	96.4	98.5
April 27 to June 27	60	2.9	97.1	98.0	97.6	97.9	99.07

Comparison of the results obtained in the periods November 12 to December 12 and January 27 to March 28 shows that the additional bacterial removal gained by increasing the available chlorine from 3.2 to 6.3 parts per million, although it is considerable in amount, is hardly commensurate with the cost. The effect of temperature on the bacterial removal is shown in the periods from January 27 to March 28 and April 27 to June 27. The mean temperature is 36° F. in one period and 60° F. in the other, while the available chlorine is practically the same in both periods, though slightly higher during the period of lower temperature. An advantage in favor of the summer results is noticeable, and it would probably have been a little greater with exactly the same amount of chlorine. Yet the results show especially that the effect of temperature on efficiency is not great. This point is of special significance in comparing the results of chlorine disinfection with those obtained with copper. In experiments with copper, temperature has been shown to produce a marked effect; in fact, the concentration of copper must be doubled during the winter months to maintain the efficiency of the process. The bacterial removals in the several groups of bacteria recorded are nearly the same, though the removal of *B. coli* is higher in all experiments. It is probably safe to assume that the removal of the typhoid and other pathogenic organisms will be as nearly perfect as the removal noted in any of these groups. The per cent removals of organisms shown by the counts at 37° C. and by the *B. coli* results probably represent most nearly the per cent removal of typhoid bacilli.

As has been stated, the reliability of a disinfection process depends quite as much on the general evenness of the results as on the average efficiency. For that reason the per cent removal of total bacteria has been computed for each of the 158 individual tests, and the results of the calculations, given in Table 19, show that the per cent removal was between 98 and 100 per cent in over half the individual tests, and that it was less than 94 per cent in only 15 per cent of the tests.

TABLE 19.—*Relation between individual tests of bacterial removal and the average result at Boston.*

Per cent of total number of tests.[a]	Per cent removal of total bacteria.	
	Not less than—	Less than—
54	98	100
19	96	98
12	94	96
6	92	94
2	90	92
3	85	90
2	75	85
2	65	75
Total, 100	Average, 96.3	

[a] Number of individual tests, 158.

The number of bacteria remaining in the disinfected effluent have been tabulated in a similar manner, in order that the bacterial quality of the final effluent may be properly understood. The results are given in Table 20.

TABLE 20.—*Relation between individual bacterial counts and the average result at Boston.*

Per cent of total number of tests.[a]	Total number of bacteria per cubic centimeter.	
	Not less than—	Less than—
47	100	10,000
23	10,000	25,000
20	25,000	50,000
5	50,000	100,000
3	100,000	200,000
2	200,000	250,000
Total, 100	Average, 24,000	

[a] Total number of tests, 158.

The average of the 158 individual tests of bacterial removal is 96.3 per cent, as compared with 96.8 per cent removal (see Table 17, p. 42) obtained from the average numbers for the whole period. The first figure is more nearly correct for estimating the efficiency of the process; but it is evident that the last figure, which is more commonly employed in such work, gives the average result with sufficient accuracy. The somewhat tedious calculation of the individual results and their variations has been made only for the total bacteria; but the results suffice to show that the average per cent removal of bacteria, computed from the average initial and final counts, is practically the same as the average of the per cents calculated from the individual tests, and that there is a certain variation in the results to the extent shown. As to the other groups of bacteria studied, it is sufficient to state that similar computations with them gave practically identical results, subject to much the same deviations.

In order to study the effect of varying the time of contact with the disinfectant, samples of the trickling-filter effluent were collected from the mixing trough after the disinfecting solution had been added. After these samples had been well shaken, determinations were made of the number of bacteria remaining at the end of ten minutes, fifteen minutes, one hour, and two hours, the sample being shaken each time before withdrawing the test portion. The number of bacteria in the effluent before treatment, as determined on a separate sample, was between 250,000 and 1,000,000 per cubic centimeter; but the numbers in all tests have been converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter for more ready comparison of the results in Table 21.

TABLE 21.—*Relation between time of contact and efficiency of disinfection with chloride of lime.*[a]

Date.	Number of remaining bacteria per cubic centimeter[b] after contact for—			
	10 minutes.	15 minutes.	60 minutes.	120 minutes.
August 6		1,100	160	150
9	2,500	190	58	7
10	10,000	270		40
11	3,500	570	154	100
14	47,000	1,100	700	570
15	4,200	310	120	120
16	1,200	240	160	130
17	9,800	800	260	150
20	400,000	12,000	7,000	5,500
21	28,000	2,100	1,300	1,000
23	1,300	230	110	31
Average	50,000	1,700	950	700
Per cent of remaining bacteria	5.0	0.17	0.10	0.07

[a] Available chlorine, 5 parts per million.

[b] All numbers converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter.

The rapidity of the action of the disinfectant is somewhat surprising, and it indicates that long periods of contact are unnecessary. It is evident that the greater part of the disinfection is accomplished within the first fifteen minutes, and that a contact period of one hour is probably ample for practical work. Another feature of interest in this experiment is its bearing on the character of the sediment in the disinfection tanks. It has been suggested that perhaps such sediment carries down with it large numbers of the bacteria that are recorded as being removed, though they may be still vigorous within the protecting body of solid matter. It is undoubtedly true that ordinary sedimentation tanks remove a considerable number of bacteria, and the actual removal is doubtless even greater than would appear from the data, owing to multiplication during sedimentation. But in their slow descent through the liquid, such bacteria are subject to the action of the chlorine, the supply of which is constantly renewed by the downward movement of the particles. The major portion of such sediment is suspended in the liquid for periods varying from fifteen minutes to an hour, during which time the chlorine has evidently ample opportunity to act. In the series of tests just described this sediment was included in the bacterial determinations. It is interesting to note, therefore, that the average reduction of bacteria at the end of two hours was 99.93 per cent, while the routine tests on the same days in the sedimentation tank gave an average reduction of 99.96 per cent, results practically identical. The sediment is apparently as completely disinfected as the supernatant liquid, but naturally an accumulation of sediment at the bottom of the tank would soon rid itself of chlorine and permit the multiplication of the remaining bacteria. Such secondary growth of bacteria, however, has no sanitary significance, since it has been satisfactorily shown that the pathogens do not develop in such manner outside the body.

These results demonstrate the entire feasibility of satisfactorily disinfecting trickling-filter effluents with chloride of lime, and they indicate that about 3.5 parts per million of available chlorine and a contact period of about one hour are ample for an effluent like that on which the experiments were made. A general discussion of the results in their practical application to the disinfection problem with special reference to costs is given on pages 63–70.

DISINFECTION OF CRUDE SEWAGE.

Under certain circumstances it may be necessary and desirable to disinfect the crude sewage of a community, though such a procedure would not as a rule be considered. It can never take the place of purification except by the use of excessive amounts of disinfectant; and by destroying the bacteria always present it simply delays the natural processes of reduction, allowing them to proceed at a later time, possibly after the solid matter has had time to settle to the bottom of a stream where the greatest nuisance will be caused by its decomposition. It might happen, however, that a sufficiently great dilution to preclude anaërobic action and a sufficiently swift current or tidal flow to prevent sedimentation would obviate all danger of a nuisance except from a bacterial standpoint. Such conditions are, perhaps, most nearly realized in our seaboard cities, where there may be no question of a physical nuisance, but where bacterial pollution of the harbor waters may be undesirable for various reasons.

The disinfection of crude sewage was studied because it was believed that experiments with the material might help to solve the general problem. The relations between available chlorine, amount of organic matter, and germicidal effect suggest that an excessive amount of organic matter in raw sewage might affect the efficiency of the chloride of lime treatment by combining directly with the chlorine and thus preventing its activity. The quality of the organic matter might also influence the result; for, as the organic matter of crude sewage is more readily oxidizable than that of an effluent, it might be expected to consume a greater amount of chlorine than the latter in a short time. The experiments with crude sewage were undertaken with the object of studying such features and of ascertaining the concentrations of chlorine necessary to effect a satisfactory removal of the bacteria in crude sewage, having in view both the possible disinfection of crude sewage itself and the establishment of a maximum limit of available chlorine in the treatment of effluents.

The details of these experiments differ somewhat from those of the effluent tests that have been described. In treating an effluent, sedimentation is an advantageous process by itself and can be usefully employed as an adjunct in disinfection, but in treating raw sewage, the removal by sedimentation of large amounts of organic matter in an unoxidized condition is undesirable and is not permissible in practice. In the experimental work, therefore, it was necessary to prevent sedimentation during the treatment.

A rectangular tank having a capacity of about 700 gallons was employed for the experiments. A 2-inch pipe led from the bottom of the tank to a pump with sufficient capacity to draw out the entire contents of the tank in half an hour. The outlet pipe from the pump discharged into the top of the tank, and the rapid circulation maintained in the sewage in this manner during the experiment made sedimentation of solids practically impossible. Before the beginning of the test the sewage was pumped through the system for fifteen minutes in order to insure thorough mixing; then a sample was collected for chemical and bacterial analysis, and the calculated amount of disinfectant solution was slowly poured into the inflowing stream. The force of this stream entering the tank from a height of about six feet churned the sewage thoroughly and assured rapid and complete mixing. Samples were collected at the end of the second and fourth hours for determination of the total bacteria growing at 20° C. and of the number of *B. coli*. The available chlorine employed was ten parts per million. In the first series of tests the total amount of chloride of lime was added at first, but in the second series it was added in four portions at hourly intervals. The results are tabulated in Table 22.

TABLE 22.—*Disinfection of crude sewage with chloride of lime at Boston; series 1 and 2.*[a]

Series.[b]	Temperature.	Number of bacteria per cubic centimeter.		
		Initial.	At end of 2 hours.	At end of 4 hours.
	°F.			
1	44	700,000	4,900	13,000
	46	260,000	220	5,700
	50	750,000	10	100
	60	600,000	620	80
	60	200,000	500	100
	60	270,000	500	100
Average	54	460,000	1,100	3,400
2	56	600,000	700	190
	60	460,000	100	60
	60	360,000	260	40
	60	460,000	14,000	340
	60	280,000	22,000	200
	60	540,000	7,000	130
Average	59	450,000	7,500	160
Number of *B. coli* per cubic centimeter; average of both series.		35,000	24	15

[a] Available chlorine, 10 parts per million.
[b] Series 1. Chlorine added at start. Series 2. Chlorine added in four equal hourly portions.

The average reduction of total bacteria in the first series was 99.76 per cent at the end of two hours, and, owing to multiplication of bacteria, 99.26 per cent at the end of four hours. In the second series the reduction in two hours was only 98.3 per cent, five parts per million of available chlorine having been added up to that time, and the addition of another five parts of chlorine brought the total reduction up to 99.96 per cent at the end of four hours. This indicates that there is a distinct advantage in adding the disinfectant in successive portions, but the increased efficiency in this case was not great, and it is doubtful whether it would generally be sufficient to compensate for the more complicated method of operation.

The figures for *B. coli* have little individual significance, but the average values indicate a removal of *B. coli* of 99.93 per cent and 99.97 per cent after two hours and four hours, respectively—values that are considerably better than those derived for the total bacteria. The results of the disinfection of crude sewage therefore agree with those obtained with the filter effluent. It is also apparent from these experiments that ten parts per million of available chlorine are ample to disinfect the crude sewage of Boston, and it is probable that even a less concentration would give satisfactory results. It is evident also that two hours is a sufficient contact period, little advantage being gained by making it longer.

In April, 1908, a third series of experiments with crude sewage was made to determine the minimum amount of chlorine and of contact time possible for satisfactory disinfection. These tests were essentially like those of the first series, except that the available chlorine was varied each day, so that on successive days it amounted to two, four, six, eight, and ten parts per million, respectively. On the sixth day it was started again at two parts. In this way the effect of chlorine concentration was studied with as little interference as possible from other variables, such as temperature and character of the sewage. A two-hour period of contact was given, and in addition to the initial sample, in each test, samples were collected after half an hour, one hour, and two hours. The results of this series are shown in Table 23.

TABLE 23.—*Disinfection of crude sewage with chloride of lime at Boston; series 3.*

Available chlorine (in parts per million).	Temperature.	Number of bacteria per cubic centimeter.			
		Initial.	One-half hour.	1 hour.	2 hours.
	° F.				
2	52	1,100,000	90,000	62,000	130,000
	58	1,600,000	320,000	470,000	870,000
	59	1,200,000	32,000	49,000	140,000
	53	900,000	47,000	16,000	42,000
	60	1,900,000	400,000	450,000	700,000
	64	1,700,000	370,000	460,000	1,000,000
4	54	2,100,000	50,000	41,000	65,000
	55	1,100,000	5,000	6,500	4,400
	59	1,400,000	30,000	40,000	85,000
	58	950,000	3,400	1,100	4,200
	60	1,900,000	12,000	11,000	23,000
	64	3,500,000	33,000	26,000	80,000
6	56	1,700,000	3,600	9,000	1,700
	58	1,700,000	6,500	600	6,000
	60	2,800,000	17,000	4,600	4,400
	57	1,700,000	1,700	8,400	3,900
	60	2,400,000	1,800	3,000	1,700
	64	3,300,000	14,000	11,000	18,000
8	55	1,600,000	570	480	600
	60	1,500,000	3,400	160	730
	59	2,000,000	2,000	1,100	3,700
	59	1,100,000	340	170	750
	63	2,600,000	1,900	2,700	3,300
	65	2,500,000	6,300	3,300	9,500
10	52	1,600,000	380	300	400
	57	610,000	200	210	200
	58	1,900,000	1,100	430	1,600
	62	1,100,000	350	800	1,100
	64	2,500,000	500	350	850
	64	3,100,000	3,500	2,300	4,800
Control	56	1,200,000	1,500,000	1,800,000	2,100,000

The results indicate that a large amount of chlorine is consumed by the sewage within two hours. Two parts per million are consumed within half an hour and ten parts per million are not sufficient to prevent the subsequent growth of bacteria. It has, however, already been pointed out that such subsequent growths have no significance and that the efficiency of the disinfection from the standpoint of the pathogenicity of the sewage is measured by the maximum reduction, independent of any subsequent increase.

The average initial and minimum figures and the per cent of bacteria removed for each concentration of chlorine are brought together in Table 24.

Table 24.—*Disinfection of crude sewage with chloride of lime at Boston; summary of results.*

Available chlorine (in parts per million).	Average number of bacteria per cubic centimeter.		Bacteria removed.
	Average initial.	Average minimum.	
			Per cent.
2	1,400,000	210,000	85
4	1,800,000	23,000	98.7
6	2,200,000	6,000	99.7
8	1,900,000	1,200	99.94
10	1,800,000	700	99.96

These experiments were not sufficiently prolonged to furnish complete data on the process, and it is not at all unlikely that at another season of the year somewhat different results might have been obtained, though it has been shown in connection with the work on effluents that the temperature effect on the disinfection itself, other conditions remaining constant, is but slight. The bacterial and chemical composition of crude sewage, however, is affected by temperature to a much greater extent than is that of filter effluents. The amount of dissolved oxygen present is an important index to the character of the sewage or the effluent in reference to its effect on chlorine; absence of dissolved oxygen in particular indicates ready oxidizability, which in turn means the rapid absorption of chlorine. It is probably true that a given amount of chlorine acting for a given time will bring about a definite reduction in the total number of bacteria, regardless of the character of the treated liquid. Unless excessive amounts of chlorine are added, however, the time of contact is determined by the character and the amount of the organic matter in the sewage; consequently the more rapidly the chlorine is exhausted by this organic matter the shorter is the time of contact and the less is the bacterial reduction. The sewage experimented with in these tests represents about an average condition in regard to reducibility, and it contained about one-half the amount of dissolved oxygen that would be found during the winter months. Results fully as satisfactory as these could doubtless be obtained during six months of the year with even less available chlorine. During the summer months, when dissolved oxygen is not present, more chlorine than is here indicated would be found necessary. The Red Bank experiments on septic sewage make it probable that a concentration of ten parts per million of available chlorine may be taken as a maximum amount during the summer.

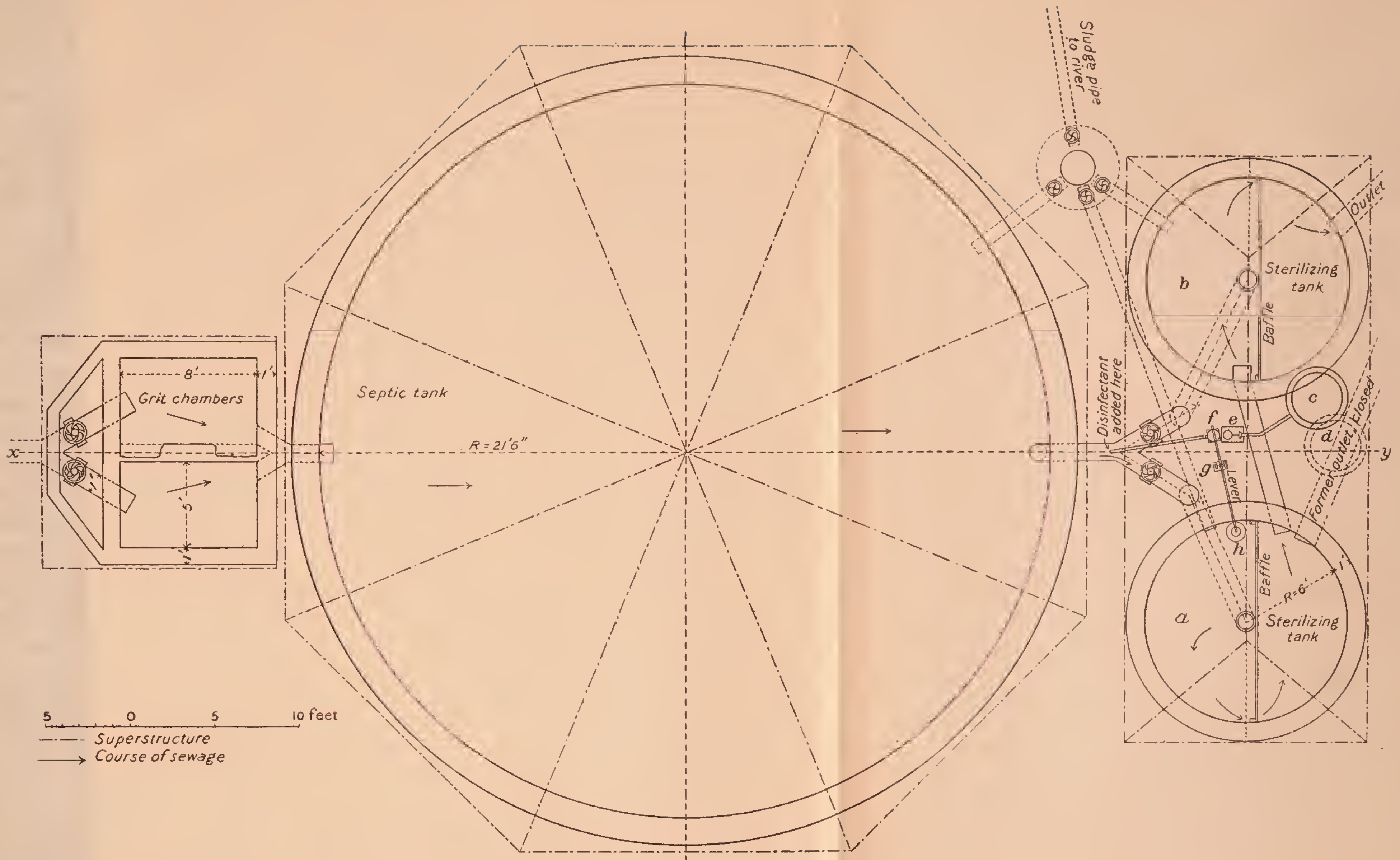
Satisfactory disinfection of crude Boston sewage can be accomplished by adding chloride of lime in such amounts that the available chlorine will amount to about five parts per million during six months of the year, and to between five and ten parts during the other six months, or an average amount during the year of seven or eight parts per million. The addition of the disinfectant in portions at intervals during the treatment yields results that are somewhat better than those obtained by adding the entire amount at once, but it is not probable that this advantage is commensurate with the additional complications involved.

DISINFECTION OF SEPTIC SEWAGE AT RED BANK, N. J.

The successful results obtained in the disinfection of trickling-filter effluents at Boston in 1906 warranted the extension of the experiments to include a practical demonstration; and that step was made possible through the cooperation of the New Jersey State Sewerage Commission. Red Bank, a town of about 6,500 inhabitants, situated on Navesink River in Monmouth County, was selected for the tests for two reasons: The works at Red Bank were so arranged that the experiment could be undertaken at a minimum expense for new construction; and, like many other communities in that section of the State, the town was discharging partly-purified sewage into waters that shortly reached important shellfish areas. A septic sewage of rather poor quality was to be treated. Work with an effluent of higher grade had been desired, but the novelty of treating a septic sewage and the immediate practical value of the results promised to make this experiment well worth undertaking. The conditions resembled those described on pages 12–13, where it was suggested that in certain localities thorough disinfection of crude or septic sewage will go far toward accomplishing all that is needful. At least the most necessary step is thus taken first, and it is a logical first step in the gradual improvement of sanitary and economic conditions along our water fronts.

It was realized that more chloride of lime would be needed than had been used in previous experiments, but how much more was not known. The Boston results with crude sewage were not available at that time, and it was to be expected that, owing to the highly unstable character of septic sewage, even more chloride of lime would be necessary than for crude sewage. The work was started in October, 1906. During the fall the disinfection apparatus was left to the care of a local attendant, and a representative of the commission visited the works twice a week to collect samples for analysis; but mechanical deficiencies in the dosing device led to intermittent and irregular dosing, so that the results obtained were far from satisfactory, and considerable time was consumed before it was learned that more than 10 parts per million of available chlorine would be required. The work was discontinued when cold weather began, but it was resumed under more favorable circumstances in the summer of 1907. A laboratory in charge of Mr. Daniels was installed at the works, and the entire experiment was then under careful observation, for samples could be taken and examined as frequently as might be desired. The results amply justified this course. The earlier work indicated the probable strength of chlorine necessary, and developed many defects and weaknesses in the dosing apparatus, all of which were remedied. The investigations that were conducted during the summer of 1907 only are reported.

The sewerage system of Red Bank is constructed on the separate plan, with special drains to carry off rain water. On account of the sandy nature of the soil and the poor construction of the sewers considerable storm water finds its way into the sewers. The average dry-weather flow of sewage is about 265,000 gallons a day. The following description of the disposal works will be more readily understood by referring to Plate I. After entering the works the sewage divides into two streams, passing through two grit chambers, each 5 by 8 feet in plan and 3 feet deep to the flow line. The flow may be entirely diverted through either tank to allow the other to be cleaned out. From these chambers the sewage flows to the septic tank, which is circular in plan, 43 feet in diameter, with a normal depth to the flow line of 8 feet 6 inches at the periphery and 5 feet at the center, the bottom being conical. Its capacity at that depth is about 82,000 gallons, or approximately an 8-hour dry-weather flow. For the purpose of these experiments, however, it was necessary to raise the flow line throughout the system 1 foot, a change that increased the capacity of the tank to about 93,000 gallons. At the side of the tank opposite the entrance pipe the septic sewage passes out through a submerged 12-inch pipe *i*, which later divides into a Y. A branch then runs downward to the bottom of each of the filters, thence horizontally to a point beneath the center, thence upward into the filter, as shown in the sectional view. The so-called filters are two in number, and each is 12 feet in diameter. Tank *a* is 9 feet deep to the flow line, with a capacity of 7,600 gallons, and tank *b* is 8 feet 3 inches deep, with a capacity of 7,000 gallons. The tanks were originally filled with stone and brick over a false bottom and were practically strainers for the removal of suspended matter. Each filter is provided with a 12-inch overflow leading to a manhole outside the building. For these experiments the filtering material was entirely removed from both tanks, one of the outlets was closed, and a cross-connection was put in to conduct the sewage from the top of the first tank to the bottom of the second. By closing the inlet valve of the latter the entire flow was made to pass through the two tanks in series. Suitable baffles were provided, as indicated in the plan, so that the entire capacity of the tanks could be utilized to the best advantage. As thus arranged, each tank held about forty-five minutes' flow, and the efficiency of the process was tested at the end of forty-five minutes and ninety minutes.



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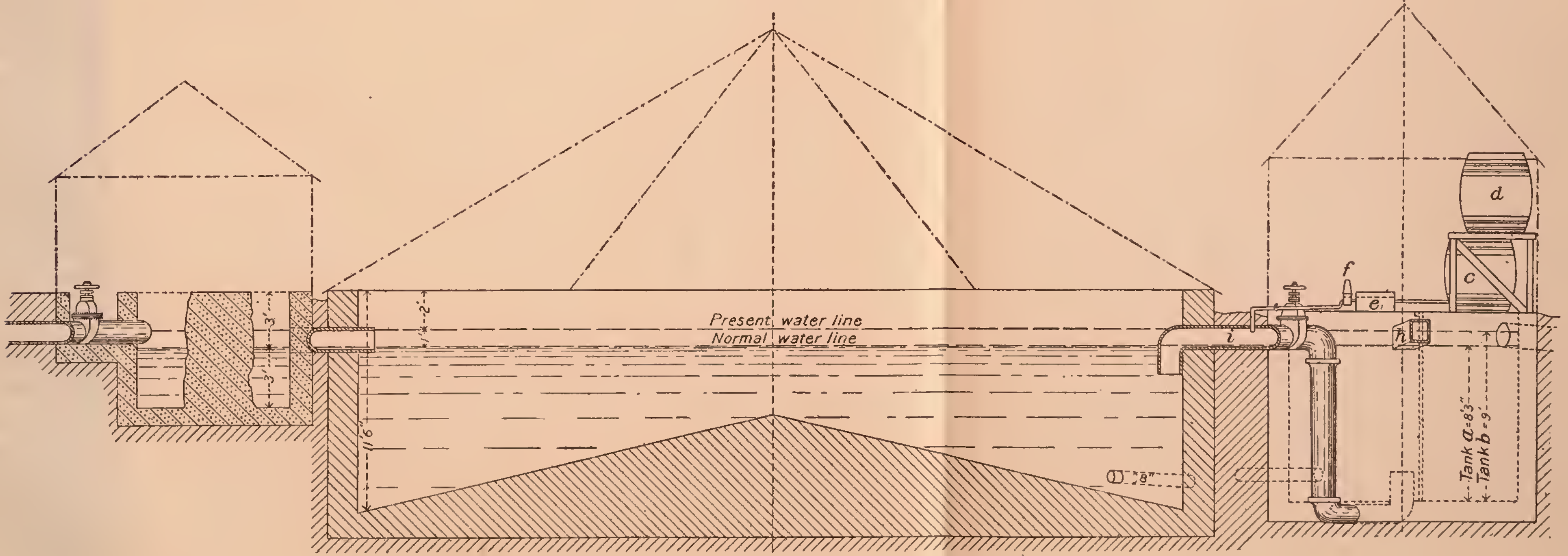

SECTION ON LINE x-y

PLAN OF SEWAGE-DISPOSAL WORKS AT RED BANK, N. J.

Chloride of lime was used throughout the work. For the preparation of the solution two hogsheads *c* and *d* of about 240 gallons capacity each were provided, one elevated over the other. In the upper hogshead the requisite amount of bleaching powder was mixed with water and allowed to settle over night. The next morning the clear supernatant liquid was drawn into the lower hogshead. The latter was connected directly with a constant-level tank *e*, controlled by a ball cock, on which a glass ball and special fittings were necessary to prevent corrosion. The constant-level tank was connected by a flexible rubber tube with the dosing tank *f*—a box 6 by 6 inches in plan and 8 inches deep—provided with a three-sixteenth-inch orifice in one side and suspended on one end of a 6-foot lever *g*, the other end of which was connected with a large float *h* in tank *a*. Tank *a* was provided at its outlet with a 1-foot weir, by which the water level was made to vary with the flow. An increase in the flow increased the elevation of sewage in the tank, thus raising float *h* and lowering the suspended box *f* at the other end of the lever. Since box *f* was connected with the constant-level tank *e*, the effect of such change was virtually to increase the head over the orifice. In this manner the flow of the hypochlorite solution was automatically kept about proportional to the flow of sewage. The ratio was not exact, because the variation in flow with the head is not the same with a weir as with an orifice, but within the range of flows used the arrangement was quite satisfactory. By discharging the sewage from tank *a* through a submerged pipe instead of over a weir the ratio between the two flows could be kept the same at all heads. A suitable gage was erected in tank *a*, and the elevation of the sewage over the weir crest was recorded at intervals of two hours from 6 a. m. to 6 p. m., or more frequently during storms. These readings were converted into gallons, and the daily discharges of sewage were calculated from them. The night flow was approximately determined by calculations based on two sets of hourly observations extending over twenty-four hours and on the relation of these sets of data to the general averages of day flows. When the weir gage was read, readings were also taken of a gage in the hogshead *c*, calibrated to read directly in gallons. By this means the hourly flows of disinfectant solution were known at all times and could be compared with the corresponding sewage flows.

The solution of bleaching powder was run into the septic tank outlet pipe *i*, where it mixed with the main flow of sewage. The treated sewage then passed through the two disinfecting tanks *a* and *b* and was finally discharged into the river. The extraction of the hypochlorite was not complete in the one leaching given it. In mills where large quantities of it are extracted three successive lixiviations are customary in order to complete the extraction, but such practice was not feasible here, and the sludge remaining each day in hogshead *d* was dumped into tank *a*, where it settled to the bottom and was slowly leached out by the sewage. In this way all the available chlorine was utilized.

It was necessary to have some information about the chemical composition of the septic sewage under treatment and to make certain chemical tests of the effluent. For this purpose samples of the septic sewage and of the disinfected effluent were collected daily and determinations of the oxygen consumed were made on them. These estimates gave a comparative indication of the strength of the sewage from day to day. Daily determinations of dissolved oxygen in the final effluent were also made, and the effluent was tested for free chlorine. The septic sewage never contained any dissolved oxygen, and under normal conditions the effluent would be in the same condition, but the application of free chlorine to sewage gives rise to chemical reactions, whereby free oxygen is formed. This is largely consumed in the oxidation of the organic matter, but nevertheless some free dissolved oxygen was always found in the effluent. The presence of this oxygen is of great value in the further self-purification of the sewage after reaching the river. Free chlorine was never found in the final effluent. Its presence would be highly injurious to fish life, and disinfection processes of this nature must always be so controlled that no injurious chemical can escape into the stream. In addition to the daily determinations just mentioned, composite sterilized samples were preserved and sent to Boston regularly, where they were submitted to complete chemical analysis. Regular chemical analyses of the bleaching powder and daily assays of the disinfectant solution were made.

The results of the work at Red Bank are given in the form of weekly averages in Table 25, and the relation between the individual and the average results are shown in Table 26.

TABLE 25.—*Disinfection of septic sewage with chloride of lime at Red Bank, N. J.; weekly averages.*

Week ending.	Available chlorine in parts per million.	Total number of bacteria per cubic centimeter at 20° C.			Number of B. coli per cubic centimeter.[a]		
		Initial.	At end of 45 minutes.	At end of 90 minutes.	Initial.	At end of 45 minutes.	At end of 90 minutes.
1907.							
July 20	9.9	800,000	410	460	46,000	4	4
27	10.6	650,000	800	420	80,000	13	11
Aug. 3	11.5	1,800,000	550	130	40,000	21	5
10	11.4	850,000	240	140	55,000	14	2
17	13.0	760,000	2,100	1,500	70,000	30	28
24	7.3	700,000	45,000	55,000	70,000	700	600
31	7.5	1,200,000	45,000	26,000	220,000	16,000	2,000
Sept. 14	11.8	750,000	13,000	8,000	300,000	150	140
21	13.1	750,000	850	800	500,000	270	260
28	10.5	700,000	120	88	550,000	80	28
Average[b]	11.5	900,000	2,200	1,400	205,000	75	60

[a] Jackson bile media used.

[b] Exclusive of period August 19–31; temperature 56° to 58° throughout.

TABLE 26.—*Relation between individual tests of bacterial removal and the average result at Red Bank, N. J.*

Per cent of total number of tests.[a]	Total number of bacteria per cubic centimeter.	
	Not less than—	Less than—
84	100	1,000
5	1,000	2,000
5	2,000	5,000
6	5,000	.....
Total, 100	Average, 1,900	

[a] Total number of tests, 224.

During the period August 19 to August 31, the available chlorine was reduced to about 7.5 parts per million. A removal of the total bacteria amounting to about 95 per cent and of *B. coli* amounting to 94.3 per cent after three-quarters of an hour and 99 per cent after one and a half hours was obtained, but the individual results were very erratic, and it was apparent that an insufficient amount of chlorine was being added. The chlorine was therefore increased again to about 12 parts per million and kept there during the remainder of the experiment. The averages in the last line of Table 25 do not include the results for the above-mentioned period. The average per cent removal of total bacteria was 99.7 at the end of 45 minutes, and the corresponding *B. coli* figure is 99.96. In 90 minutes the average per cent removals were 99.8 and 99.97, respectively. It is rather striking that such results can be obtained with 12 parts per million of available chlorine, while the results are poorer and very erratic with 7.5 parts. The explanation is probably found in the character of the sewage, which was very concentrated in its raw state and had passed through a septic tank that was working vigorously. A large amount of hydrogen sulphide was contained in the septic sewage. The characteristic odor of this substance was extremely noticeable in the vicinity of the works, and the addition of chlorine to the sewage produced a milkiness, due to the liberation of free sulphur. Titration of the septic sewage in the cold with potassium permanganate, a substance less easily reduced than chlorine, indicated that enough hydrogen sulphide and other easily oxidizable substances were present to reduce instantly about five or six parts per million of chlorine. Consequently the efficient results in this experiment were in reality obtained with about six parts of available chlorine and the poor ones with about three parts.

The disinfection of septic sewage evidently requires so much chlorine that the expense will be considerable. It will probably be found to take twice as much chlorine for septic sewage as for the corresponding crude sewage. The combination of septic action and disinfection eliminates the suspended matter and the bacteria from the sewage and in many localities would constitute a very desirable system. In practice, however, the order of the processes should be reversed. The disinfection of the crude sewage can be done in a small tank of an hour's capacity. The disinfectant should be so regulated that little or no chlorine would flow into the septic tank. Unless a considerable amount of chlorine should thus escape at one time there would be no objectionable effect on the action in the tank. There would be a great multiplication of bacteria in the tank, so that the number in the final effluent would probably be as great as in the raw sewage, and perhaps even greater. Nevertheless, the disinfection would be as effective on the pathogens as if it were applied as a final process. The subsequent development of saprophytes would have no sanitary significance and would doubtless be of real value in the subsequent self-purification of the organic matter after it had been discharged into the stream.

DISINFECTION OF TRICKLING-FILTER EFFLUENT AT BALTIMORE.

Reference was made in the history of the experiments to the cooperative arrangement between the United States Geological Survey and the Baltimore sewerage commission. In December, 1907, the sewerage commission undertook a study of disinfection methods at its Walbrook testing plant. The writer assisted in planning this work, and was consulted from time to time during its progress. The disinfection experiments were made a part of the routine work of the testing station, and they were carried out by the station staff. A complete review of this investigation, the most important and most comprehensive one on the subject ever conducted, will, it is hoped, be made by the sewerage commission in the near future. The present report has been made as brief as possible and includes only the work done before June 30, 1908.

The Walbrook testing plant, in the extreme western section of Baltimore, was built for use in investigating certain problems in connection with the disposal works now being built at Back River, the main features of which—screening, sedimentation, treatment on trickling filters, and final sedimentation—had already been decided upon. Information was specially desired as to the probable bacterial efficiency of such a process and as to the necessity for further treatment of the effluent, because the statutes of the State of Maryland require rather high bacterial efficiency. As a detailed description of the testing plant has already been published,[a] it is sufficient to state that a small section of the city was sewered and that sewage amount-

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[a] Eng. News, vol. 57, 1907, p. 235.

ing to about 50,000 gallons a day was brought to the plant and treated by a system comprising a grit chamber, a septic tank, trickling filters, and sedimentation tanks. Trickling filters of several depths and sizes of material are employed. The sewage is rather stronger than ordinary city sewage and is very fresh. The effluent used in the disinfection studies came from a filter 12 feet deep, built of crushed stone ranging in size from 0.5 inch to 1.5 inches. The rate of filtration fluctuated with the flow of sewage, but it averaged about 3,000,000 gallons an acre a day. The effluent was conducted to a sedimentation basin designed to give a two hours' flow. The disinfectant employed throughout this investigation was chloride of lime, dissolved and added to the effluent in practically the same manner as at Boston, as the effluent left the filter drain. The disinfecting solution and the effluent mixed during the short flow through a pipe to the sedimentation basin.

Monthly averages of the analyses of this effluent as it left the filter and after disinfection and sedimentation are given in Table 27.

TABLE 27.—*Chemical analyses of trickling-filter effluent at Baltimore before and after disinfection with chloride of lime and sedimentation: monthly averages.*

[Parts per million.]

INITIAL.

Month.	Suspended solids.		Organic matter.		Nitrogen as—			Oxygen consumed.[a]
	Total.	Loss on ignition.	Total.	Solids.	Free ammonia.	Nitrites.	Nitrates.	
1908.								
January	56	35	8.3	5.9	7.4	0.48	17	16
February	38	25	8.0	6.8	6.8	.13	17	17
March	53	31	8.9	7.5	5.5	.30	19	16
April	42	28	10.0	9.0	7.5	.08	21	18
June	33	21	7.0	6.5	4.0	.40	20	13
Average	45	28	8.4	7.1	6.2	.28	19	16

FINAL.

Month.	Suspended solids.		Organic matter.		Nitrogen as—			Oxygen consumed.[a]
	Total.	Loss on ignition.	Total.	Solids.	Free ammonia.	Nitrites.	Nitrates.	
1908.								
January	38	26	8.5	6.2	7.2	0.49	16	15
February	25	17	6.8	5.8	6.8	.12	17	17
March	26	17	7.9	7.1	5.5	.19	20	15
April	34	20	9.6	7.6	7.9	.08	22	18
June	21	16	7.0	6.5	4.0	.25	20	13
Average	29	19	8.0	6.6	6.3	.23	19	16

[a] Thirty-minute boiling method.

Initial and final bacteriological samples were collected as usual. Bacterial counts were made three times a day for five days each week and twice on Saturday. *B. coli* determinations were made twice daily. The results are shown in Tables 28, 29, and 30. Table 28 gives the average weekly results; Table 29 shows the relation between the removal of bacteria in individual samples and the average removal; Table 30 indicates the relation between the number of bacteria in the individual samples and the average number.

TABLE 28.—*Disinfection of trickling-filter effluent with chloride of lime at Baltimore; weekly averages.*

Week ending—	Temperature.	Available chlorine (parts per million).		Total number of bacteria per cubic centimeter at 20° C.		Total number of bacteria per cubic centimeter at 37° C.		Number of acid formers per cubic centimeter at 37° C.		Number of B. coli per cubic centimeter.[a]	
		Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.	Initial.	Final.
1908.	° *F.*										
Jan. 4	50	3.5	......	170,000	1,600	70,000	600	8,000	107	3,800	59
11	45	2.0	......	90,000	6,500	5,500	200	3,000	58	1,700	380
18	48	1.9	......	120,000	3,300	3,100	250	2,200	165	3,400	240
25	47	2.0	......	160,000	1,900	2,000	95	900	8	1,300	45
Feb. 1	40	2.6	1.3	120,000	2,200	1,900	73	950	4	2,000	490
8	43	2.5	1.1	70,000	4,100	1,000	70	400	4	600	470
15	46	0.94	0.1	80,000	11,000	1,500	400	700	90	440	330
22	45	1.4	0.4	65,000	20,000	4,000	440	3,000	180	750	70
29	45	1.5	0.4	100,000	4,600	3,000	100	1,100	17	2,400	210
Mar. 7	46	2.0	0.6	80,000	1,000	1,400	80	900	2	1,600	150
14	47	1.7	0.4	80,000	1,700	1,000	60	500	3	1,400	180
21	49	2.0	0.4	100,000	1,300	1,100	80	600	15	2,600	180
28	52	2.1	0.3	150,000	1,700	2,400	160	1,500	3	800	210
Apr. 4	50	1.7	0.4	120,000	1,800	4,100	120	2,100	10	2,100	220
11	55	2.6	1.1	140,000	1,100	2,800	70	1,900	2	3,700	39
18	54	2.2	0.6	120,000	2,500	13,000	110	3,600	25	5,500	55
25	56	2.6	0.3	120,000	2,100	18,000	350	7,000	110	2,200	200
May 2	58	3.1	......	130,000	1,200	3,500	110	2,400	3	1,400	130
9	56	2.8	1.0	160,000	2,300	2,200	70	1,600	9	1,800	43
June 13	66	2.3	0.4	120,000	17,000	21,000	3,600	9,500	[b] 730	600	100
20	67	2.3	0.8	115,000	1,300	1,800	440	300	18	3,000	300
27	67	1.9	0.1	190,000	3,700	2,900	1,100	430	0	800	400
Average	51	2.2	0.6	120,000	4,300	7,500	390	2,400	70	2,000	200

[a] Jackson bile media used.

[b] High average due to one count of 8,000.

TABLE 29.—*Relation between individual tests of bacterial removal and the average result at Baltimore.*

Per cent of total tests.[a]	Per cent of bacterial removal.	
	Not less than—	Less than—
69	98	100
14	96	98
6	94	96
0	92	94
2	90	92
2	85	90
4	75	85
1	65	75
1	40	65
1	..	40
Total, 100.	Average, 95.5.	

[a] Total number of tests, 255.

Table 30.—*Relation between individual bacterial counts and the average result at Baltimore.*

Per cent of total tests.[a]	Number of bacteria per cubic centimeter.	
	Not less than—	Less than—
36	100	1,000
35	1,000	2,000
8	2,000	3,000
3	3,000	4,000
4	4,000	5,000
2	5,000	6,000
2	6,000	8,000
3	8,000	10,000
7	10,000	......
Total, 100.	Average, 4,300.	

[a] Total number of tests, 255.

The average of the individual bacterial removals is 95.5 per cent. The per cent removal calculated from the average numbers in Table 28 is 96.6 per cent. The average efficiency, as in the Boston experiments, may be expressed in the latter form with sufficient accuracy, and this shorter method is employed in the other bacterial computations, by which the efficiencies in Table 31 were obtained.

Table 31.—*Average bacterial removal during the disinfection of trickling-filter effluent at Baltimore.*

	Per cent.
Total bacteria at 20° C	96.6
Total bacteria at 37° C	94.9
Acid formers at 37° C	97.0
B. coli[a]	90.0

The average results agree practically with those obtained at Boston. The trickling-filter effluent at Baltimore was of better quality than that at Boston and less chlorine was used. The average amount of available chlorine was 2.2 parts per million, as compared with 3.4 parts at Boston. Though the average reduction of total bacteria at both places was practically the same, the variations were greater at Baltimore, and they indicate that a somewhat greater amount of chlorine would materially improve the results. It is probable that three parts per million of available chlorine are best for treating this effluent. The *B. coli* results are not in harmony with the rest of the figures. In all the work at other places the removal of *B. coli* has been without exception better than the removal of the total organisms. Soon after the beginning of the Baltimore studies it was noticed that the removal of *B. coli*, as indicated by the bile test, was far less perfect than the general results, but efforts to discover the cause of the discrepancy were only partly

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[a] Jackson bile media used.

successful. Complete identification of *B. coli* was carried out for a period, and the results seem to indicate that many of the positive tests after disinfection are due to the presence of an organism other than *B. coli,* which fermented the bile medium. Similar atypical results were obtained in the initial samples, but not in such large proportion. The evidence of other work under the direction of the author indicates that in these experiments the removal of *B. coli* is better shown by the removal of acid-forming bacteria than by the bile test. The results as a whole demonstrate the entire feasibility of the process and the possibility of obtaining practical disinfection at a reasonable cost.

COMPARATIVE GERMICIDAL EFFICIENCIES OF CHLORINE AND SOME OF ITS COMPOUNDS.

Only a small amount of accurate data was at hand for the comparison of the germicidal efficiency of chlorine in its various forms. Accordingly, three series of comparative tests were made upon trickling-filter effluents for the purpose of obtaining such information. The results of these studies are collated in Table 32, each figure of which is the average of from three to twelve tests reduced to a uniform basis of one million initial bacteria per cubic centimeter.

TABLE 32.—*Relative germicidal properties of chlorine and some of its compounds.*

[All numbers converted to a uniform basis of 1,000,000 initial bacteria per cubic centimeter.]

Series.	Source of chlorine.	Available chlorine (in parts per million).	Total number of remaining bacteria per cubic centimeter.		
			At end of 30 minutes.	At end of 1 hour.	At end of 2 hours.
I	Free chlorine	3	650	390	280
	Sodium hypochlorite	3	500	270	230
	Potassium hypochlorite	3	410	260	280
	Potassium chlorate	3	800,000	900,000	1,000,000
	Potassium perchlorate	3	750,000	1,400,000	1,800,000
II	Free chlorine	2	17,000	13,000	17,000
	Sodium hypochlorite [a]	2	15,000	6,000	6,000
	....do.[b]	2	4,600	2,100	3,400
III	Free chlorine	2	19,000	18,000	23,000
	Sodium hydroxide and chlorine [c]	2	23,000	14,000	19,000
	....do.[d]	2	22,000	12,000	18,000
	....do.[e]	2	23,000	9,000	10,000
	....do.[f]	2	19,000	7,500	8,000

[a] Electrolytic.
[b] From bleaching powder.
[c] Chlorine added thirty minutes after the hydroxide.
[d] Chlorine added twenty minutes after the hydroxide.
[e] Chlorine added ten minutes after the hydroxide.
[f] Chlorine added with hydroxide.

In series I comparison is made of free gaseous chlorine generated electrolytically, sodium hypochlorite, and potassium hypochlorite. Potassium chlorate and potassium perchlorate are also included, because they are formed in many direct electrolytic processes. The available chlorine of the two latter compounds is taken in an electrolytic equivalent sense, and would be better expressed by the term "oxidizing power." Three parts per million of available chlorine were used in all the tests of series I.

In series II comparison is made of free gaseous chlorine, potassium hypochlorite prepared from bleaching powder, and the same compound electrolytically prepared by the recombination of the products of the electrolytic cell. In this and in the next series two parts per million of available chlorine were used, because it was found that comparisons are more readily made where the disinfection is not so nearly complete.

In series III free chlorine was again used and was compared with the electrolytic hypochlorite. In this set of experiments, however, the hypochlorite was made in the sewage by adding separately the chlorine water and the sodium hydroxide. In three sets of tests the addition of the hydroxide preceded that of the chlorine by ten, twenty, and thirty minutes, respectively. The object of this procedure is to determine whether the caustic soda and the gaseous chlorine possess separately better penetrating powers than the hypochlorite does. If such were the case, formation of the hypochlorite within the solid particles of the sewage might result in more complete disinfection than could otherwise be obtained.

The results indicate plainly that hypochlorites are the most efficient germicides. Gaseous chlorine is almost as good, but in each series the free chlorine is somewhat inferior to the hypochlorite. Chlorates and perchlorates have almost no value in disinfection. The formation of these compounds in the electrolytic cell is, therefore, a total waste of energy, and should be prevented as far as possible. Production of these compounds explains in large measure the inefficiency of hypochlorite cells. Hypochlorites made electrolytically are slightly inferior to the market product, but this difference would probably be inappreciable in large-scale tests, where the conditions under which the hypochlorites are prepared are more nearly those of commercial practice. Hypochlorites of different bases evidently have the same value; the results obtained with the sodium and the potassium salts are practically identical and are similar to those obtained in practice with the calcium salt. The claim that the magnesium compound is more efficient than the calcium compound was not investigated. Hypochlorites can be made advantageously by mixing dilute solutions of free chlorine and sodium hydroxide, the products of the electrolytic cell, but the mixing should take place either in the sewage or in cold dilute solution, as otherwise chlorates and perchlorates will be formed; if the hydroxide is added a short time before the chlorine, it is removed from the solution, leaving free chlorine uncombined and leading to a more rapid exhaustion of the available chlorine.

These tests have an interesting bearing on the question of the exhaustion of the chlorine. It appears that the chlorine attacks the organic matter and the bacteria simultaneously, but that its effect on the former is a direct function of its concentration, while its germicidal effect does not bear such exact relation. If these are the true conditions, the successive addition of small portions of chlorine, or what amounts to the same thing, the addition of a substance that yields chlorine slowly, prevents the rapid reduction of the chlorine by the organic matter and prolongs the time of contact with the bacteria. In series III, Table 33, more or less of the hydrate was consumed in saponification before the chlorine was added, the amount so removed depending on the time that elapsed between the addition of the hydroxide and the addition of the chlorine. The first set of series III, therefore, represents the action of free chlorine, and the last set the action of hypochlorite, with the intermediate tests representing different proportions of the two substances. The progressive nature of the final results indicates strongly the necessity of having the chlorine combined in such form that its action on organic matter is retarded. The same effect is shown in the work on crude sewage described on pages 37–51. In the experiments reported in Table 22 decidedly better results were obtained by adding the hypochlorite in four equal portions at hourly intervals than by adding the entire amount at once. In practice the effluent to be treated should never be acid in reaction; it is probable that the addition of lime would still further decrease the rate of decomposition of the hypochlorite and increase its bactericidal efficiency.

EFFECT OF CALCIUM HYPOCHLORITE ON COLON AND TYPHOID BACILLI.

The colon bacillus has been employed in this and in other work as a convenient test organism with which to measure the efficiency of the disinfection process. For obvious reasons experiments on a large scale with the typhoid bacillus are out of the question. Consequently, a comparison was made between the relative resistance of the typhoid and the colon bacilli under controllable conditions, with the idea that in practice the effect of the disinfection process on the former could be measured by its effect on the latter. Emulsions of the two organisms in tap water were treated with hypochlorite solution, and the parallel tests with the two species were made at the same time and were kept as nearly alike as possible. The number of bacteria per cubic centimeter was determined at the end of twenty, forty, and sixty minutes, and two, four, and eighteen hours, and twelve tests of each kind were made in the same manner. The available chlorine ranged from 3.5 to 6 parts per million, averaging 5 parts. The results of the individual tests varied greatly from day to day, because, no doubt, of difference in the character of the growths and in the amounts of organic matter introduced with the organisms. Yet the average figures obtained from these twelve sets of tests probably give a fair basis for estimating the comparative resistance of the two organisms to the disinfectant. The per cent removal has been calculated and the average results are presented in Table 33.

TABLE 33.—*Comparative resistance to calcium hypochlorite of B. typhi and B. coli in aqueous emulsion.*[a]

Tests made at end of—	Removal of bacteria (per cent).	
	B. typhi.	B. coli.
20 minutes	90.5	92.0
40 minutes	98.2	98.0
1 hour	99.45	99.53
2 hours	99.60	99.70
4 hours	99.92	99.96
18 hours	99.99+	99.99+

[a] Average available chlorine, 5.0 parts per million.

The slight differences shown by the experiments on the two organisms may be attributed to experimental variations. The work is not conclusive because other strains of organisms might have yielded different results, but it indicates in a general way that *B. coli* may reasonably be regarded as test organisms in disinfection work and that the process may be expected to destroy typhoid organisms present at least as thoroughly.

It is interesting also to note that the per cent removal of *B. coli* after four hours is about the same as that recorded in the experimental disinfection of crude sewage; namely, 99.96 per cent as compared with 99.93 per cent.

PRACTICAL APPLICATIONS AND COSTS OF DISINFECTION.

The experiments that have been described were sufficiently prolonged and varied in their scope to justify the application of the chloride of lime treatment to practical disinfection on a large scale. It is not possible, however, to draw general conclusions regarding the amount of chlorine necessary for the disinfection of effluents, much less of crude sewage, because the dose is determined largely by the character of the organic and reducing matters contained in the sewage or the effluent. But the investigations have shown what may be accomplished under several conditions and they have established certain probable maximum amounts of chlorine for particular classes of sewage and effluents. They have demonstrated, for example, that trickling-filter effluents similar to those tested may be satisfactorily disinfected with three or four parts per million of available chlorine, and that such quantity will usually be sufficient to effect the removal of 95 per cent or more of the total bacteria in the effluent. If the effluent should contain only 25 per cent of the original sewage bacteria, the whole purification process would result in a removal of 98.8 per cent of the total number of bacteria. The per cent removal of *B. coli* and of typhoid organisms will be at least as high if not higher. Crude Boston sewage can be disinfected to about the same extent with from four to six parts per million of available chlorine. It may reasonably be inferred, therefore, that five parts per million of chlorine represent the maximum concentration that would ever be necessary for the disinfection of a fairly stable effluent, since no such effluent would contain as much oxidizable organic matter as the crude sewage that is treated. The septic sewage of Red Bank probably represents a maximum condition for crude sewage, because its high content of hydrogen sulphide and other oxidizable matters would probably never be exceeded in crude sewage, or at least in sewage from American cities. The disinfection of crude sewage, therefore, would require four to twelve parts per million, of available chlorine, depending on the character of the sewage and its content of oxidizable matters. It will probably be undesirable to treat septic sewage, but if such sewage should be treated, from ten to fifteen parts of chlorine, or perhaps more, would be necessary. The extreme variability of the composition of septic sewage makes it almost impossible to fix a maximum limit for the amount of hypochlorite. The amount of disinfectant required in any plant would necessarily be determined before final adoption of the plan, but these estimates will serve as useful guides, and the limits assigned include the majority of probable conditions.

No data have been obtained with effluents of higher degree of purity than those from trickling filters. The general conclusions from the work have been that the disinfectant action is a function of the chlorine concentration and of the time of contact, and that the time is determined largely by the rate at which the chlorine is consumed by the organic matter. Effluents of a better grade would probably require the same amount of chlorine, if the disinfection were to be accomplished within two hours. In the effluents with which experiments were made, the chlorine was practically consumed in two hours, but in a purer effluent chlorine would probably be left. This indicates that somewhat smaller quantities could be used with longer storage periods. A point is soon reached, however, beyond which the cost of storage is greater than the saving in disinfectant. Effluents of high degree of purity could probably be disinfected with one part of available chlorine, but a contact period of at least five hours would be required for satisfactory removal of the bacteria. One part is probably the minimum amount of chlorine that can be used, as the necessary time of contact increases very rapidly with decreasing concentration of chlorine.

One of the most important practical points that has been developed is the relation between organic matter, time of contact, and amount of chlorine necessary. Obviously a definite concentration of chlorine acting for a given time will bring about a definite result independent of the nature of the solution. If, however, chlorine is being consumed by the solution itself a greater amount will have to added at first in order to maintain the same average concentration. On the other hand, longer periods of contact with lower chlorine concentration are possible with the better grades of effluent. The experiments with various kinds of sewage make it possible to formulate a crude rule, which may be stated as follows: The product of the initial concentration multiplied by the time in hours required for complete reduction of the available chlorine should be about five for satisfactory disinfection, except that the contact period must not be less than half an hour in any case.

It is possible to fix within narrow limits the cost of chlorine disinfection. The cost is determined chiefly by the concentration of chlorine necessary and the related factor of contact period, and secondarily by the size of the plant. The unit used in the following summary of costs is a plant with a daily flow of 5,000,000 gallons of sewage, such a plant being the smallest that would require the entire time of an attendant, a part of whose salary may legitimately be charged to disinfection. On larger works the labor costs would increase proportionately, and on smaller works arrangements would naturally be made by which the plant could receive proper attention in connection with the regular work of the sewer or street department. The price of bleaching powder has been estimated at $24 a ton delivered at the plant; it is quoted at from $22 to $25, and a price as low as $20 is obtained on large orders by certain paper mills. The price taken is, therefore, sufficiently high to cover the cost of the moderate-sized shipments that would be required for a 5,000,000-gallon plant. A 50,000,000-gallon plant could obtain its bleaching powder for at least 10 per cent less. This bleaching powder would contain over 35 per cent available chlorine, but in order to allow for waste 33 per cent has been taken as the average figure. Labor is computed at $2 for an eight-hour day. Two hours a day—an ample allowance—are reckoned for the care of a 5,000,000-gallon disinfecting plant using 5 parts or less of chlorine. For over 5 parts the time would increase proportionately. Interest, depreciation, and other fixed charges are computed as 6 per cent of the cost of the additional works made necessary by the disinfection treatment; as the construction is chiefly masonry, but little depreciation need be allowed. In certain projects sedimentation tanks would already be available, so that the application of disinfection would not require the construction of storage tanks. For this reason the item storage tanks has been separated from the other fixed charges that include 6 per cent of the cost of mixing tanks and storage tanks for the solution, pumps, piping and connections, and suitable housing. In handling the chemicals for a plant requiring 3 parts per million or more of chlorine, some form of power mixer would be economical, and that item has been estimated. In small plants the mixture of bleaching powder and water would be settled and the solution decanted, but in the larger works the whole mixture would be used, and it would require constant stirring. The increased power item would be more than counterbalanced by the saving in tank construction. Table 34 contains a summary of the cost estimates for chlorine concentrations from 1 to 15 parts per million.

Table 34.—*Estimates of the cost of maintenance and operation of a plant for disinfecting sewage or effluent with chloride of lime, based on a capacity of 5,000,000 gallons a day.*

Available chlorine in parts per million).	Time of contact (in hours).	Cost per million gallons.					
		Storage tanks.	Other fixed charges.	Bleaching powder.	Labor.	Power.	Total.
1	5.0	$0.10	$0.02	$0.30	$0.10	....	$0.52
2	2.5	.05	.04	.60	.10	....	.79
3	1.6	.04	.05	.90	.10	$0.02	1.11
4	1.2	.03	.07	1.20	.10	.02	1.42
5	.8	.03	.08	1.50	.10	.03	1.74
10	.5	.02	.16	3.00	.15	.06	3.39
15	.5	.02	.24	4.50	.20	.09	5.05

The estimates made for a 5,000,000-million-gallon unit can be safely applied to larger works, and they are applicable within reasonable limits to small works that are properly managed. The cost of the tanks and of covering them would become proportionately cheaper with increased size, but this saving would be offset by the advisability of better construction and architectural embellishment. The saving due to decreased price of bleaching powder for a 50,000,000-gallon plant, using 3 parts per million of chlorine, would be about $4.50 a day, which would approximately pay for the additional chemical and bacteriological control required by a plant of such size. On very large works labor items would not increase proportionately, because most of the work would be done by machinery.

In an earlier paper[a] the opinion was expressed that the expense might be considerably reduced and efficiency increased by using

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[a] Phelps, E. B., and Carpenter, W. T., The sterilization of sewage filter effluents: Tech. Quart., vol. 19, 1906, p. 382; Contr. from Sanitary Research Lab., vol. 4, 1908.

electrolytic chlorine produced at the disposal works instead of bleaching powder. The relation of electrolytic processes to sewage disinfection is still unsettled, but a study of the present possibilities of such processes and experimental work with the McDonald cell and with small cells of special design have indicated that the margin of cost between the alternative methods is so slight that it hardly justifies the additional effort and the uncertainty involved in the establishment of an electrolytic plant. A brief discussion of recent developments in this field will show the reasons for this conclusion. Two general types of electrolytic process are available, in both of which the electric current is passed through a solution of sodium chloride, chlorine being liberated at one electrode and caustic soda at the other. In one type these products are allowed to recombine, forming sodium hypochlorite and certain other compounds. In the other type the products are removed from the cell as quickly as possible, the aim being to prevent their recombination. Numerous processes of the first kind have been developed, of which the Hermite and Woolfe processes have already been mentioned. The commercial preparation, called "Chloros," is made in this way. The most recent, and probably the most improved, cell of this type has recently been described by Digby and Shenton.[a] The reaction by which the hypochlorite is produced from chlorine and caustic soda in cold dilute solution is:

$$(1)\ 2\,NaOH + 2Cl = NaOCl + NaCl + H_2O.$$

In the paper just cited Digby proposes the reaction,

$$(2)\ NaOH + Cl = NaOCl + H.$$

He bases his view on the observation that the electro-chemical efficiency of the cell is over 50 per cent. Aside from the obvious impossibility that a reaction can produce at one and the same time nascent hydrogen and a strong oxidizing agent, it is apparent that reaction (1), if it were carried out completely, would yield a product containing not 50, but 100 per cent of the available chlorine initially present. The conception that this reaction represents a loss of half the available chlorine is due apparently to a mistaken idea of the term available chlorine, which, as has been explained on page 18, is really a misnomer. The fact is that the oxidizing power, or the available chlorine as ordinarily determined, of the products of reaction (1) is equivalent to twice the chlorine of the hypochlorite, or to the total chlorine present. There is, therefore, no apparent basis for the reaction proposed by Digby, which would yield twice as much available chlorine as the amount allowed by the law of electro-chemical equivalents. The reactions of equation (1) are complete only in cold

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[a] Digby, W. P., and Shenton, H. C. H., Surveyor, vol. 30, 1906, p. 653.

dilute solutions. If the solution is hot or if it is concentrated chlorates and perchlorates are produced simultaneously. It is for this reason that the disinfectant value of these two sets of compounds was determined in an earlier part of the present investigation. It was found that they possess practically no disinfecting power and that their production in the cell represents a loss of energy. Economy in electric current demands strong salt solutions and high current densities with consequent heating of the electrolyte. Electrical efficiency is, therefore, opposed to chemical efficiency, and the problem in designing cells of this type is to balance the two efficiencies in the most economical manner. The electro-chemical equivalent of a current of one ampere is 1.32 grams an hour of chlorine, and this equivalent is not modified by the voltage. However, as the total energy employed in a process determines its cost, it is necessary to consider voltage as well as current in discussing electrolysis. In any electrolytic reaction there is a definite minimum voltage required for carrying out the reaction, and this can be computed from thermal considerations as follows: The complete reaction in the cell before the recombination of the hydroxide and the chlorine may be written,

$$\mathrm{NaCl} + \mathrm{H_2O} = \mathrm{NaOH} + \mathrm{H} + \mathrm{Cl}.$$

Substituting the heats of formation of these compounds gives

$$964 + 684 = 1118 + x, \text{ whence}$$

$$x = 530 \text{ calories (K).}$$

Here x is the heat required by the reaction, expressed in calories (K) per gram-equivalent of the reacting substances, and its value is 530 calories. One gram-equivalent of substance is transformed with the passage of 96,540 coulombs of electricity, and one coulomb transferred under a difference of potential of one volt has an energy equivalent to 0.00241 calories. Therefore, one electro-chemical equivalent of current at a difference of potential of one volt has a heat value of 96,540 multiplied by 0.00241, or 232.7 calories. Consequently the voltage required to effect the desired reaction, which calls for a heat absorption of 530 calories per equivalent, is 530 divided by 232.7, or 2.28 volts. This is the minimum voltage with which the reaction can take place, and efficiency calculations to an energy basis must be referred to this voltage. At a difference of potential of 2.28 volts, one kilowatt gives 439 amperes, so that an output of 579 grams of chlorine per kilowatt-hour represents a process of 100 per cent efficiency on both a current and an energy basis. In practice a current at a tension of at least 4.5 volts is usually found necessary, even with strong solutions of salt and with electrodes placed as near together as possible. This factor alone reduces the energy efficiency to 55 per cent with perfect current efficiency. The current efficiency depends especially on the design of the cell. If there are no complicating secondary reactions during the recombination of the products it approaches 100 per cent very closely, and this is also the case in the most improved design of chlorine cell in which recombination does not take place. It is clear that the production of hypochlorite in one operation within the cell is not economical, and a review of the available information and a laboratory study of various hypochlorite cells have led to the conclusion that cells of that type can not be expected to yield much more than one-half the available chlorine that can be obtained from the same electric current by means of direct chlorine cells.

Direct chlorine cells have been developed to a high degree of efficiency, and this is the type of cell which has been considered in the present studies of sewage disinfection. The McDonald cell, which was used to some extent in this work, is giving in a regular installation in a large paper mill a current efficiency of over 80 per cent at 4.5 volts, making the total energy efficiency over 43 per cent. The most recent development is the Townsend cell, for which current efficiencies exceeding 98 per cent are claimed at a tension of 5 volts or more. The special feature of the Townsend cell is an arrangement by means of which the caustic liquor drops into a bath of oil as soon as it is formed, a step that prevents recombination. In spite of the high efficiency of such cells, it is not practicable to employ them in sewage work on account of the small margin between the market cost of chlorine and the cost of its manufacture electrolytically. This condition is due to the fact that the demand for caustic soda is so much greater than that for chlorine that the chlorine is to a certain extent a by-product and can be made into bleaching powder and sold at low cost. On the other hand, the manufacture of small amounts of caustic liquor at the disposal works does not warrant the installation of the necessary machinery for the production of pure caustic soda; consequently, without a market for this by-product, the cost of the chlorine would be the entire cost of the operation. In addition, a skilled chemical engineer who would be required would increase the cost per million gallons much more in a small plant than in a large one, while the uncertainty of the process and the increased responsibility on the sewage works both offset any slight advantage in cost which might appear in favor of the electrolytic plant. It has also been made clear in the present studies that the use of free chlorine, as contemplated in the earlier plan, is not economical and that some base should be provided for the preparation of hypochlorite. This base might be the caustic soda yielded by the process, or if a market for that by-product were available, lime could be used.

For the reasons outlined, therefore, this investigation of the possibilities of the electrolytic processes indicates that, contrary to earlier views, such processes are not well adapted at the present time to sewage disinfection. Nor does it seem probable that hypochlorite from cells in which the products are allowed to recombine within the cell will ever be able to replace ordinary bleaching powder.

CONCLUSION.

The main reason for disinfecting sewage lies in the probable effect of discharging pathogenic bacteria into lakes, rivers, and harbors. Any such discharge is obnoxious to the sanitarian, and when the practice of computing the cost of typhoid-fever epidemics becomes more general the cost of disinfecting sewage will not appear excessive. At present, however, the demand for sewage disinfection is confined to two conditions, namely, the possible pollution of water supplies and of shellfish beds. It has not yet been decided upon whom the responsibility rests for protecting domestic water supplies. The sanitarian recommends that rivers be kept as clean as possible and that water be filtered, but in practice distinction is made between supplies which are filtered before use and those which are not, and complete disinfection of sewage that enters streams from which supplies of the first kind are derived is still regarded as an unreasonable demand. The concensus of competent opinion requires at least, however, that, if an effluent is discharged within the region of important shellfish beds or into a stream which is used as a source of domestic water supply without filtration, such effluent shall be free from pathogenic germs. Improved standards in sanitation and improved methods of disinfection will both operate to increase these minimum requirements, but in the meantime a thorough knowledge of disinfection methods and experimentation on the improvement and the cheapening of such methods will do much to hasten their general adoption. Slow sand filtration removes bacteria in a satisfactory manner and almost totally eliminates organic matter. Under certain conditions such a result is highly desirable, but the method is comparatively costly, especially in the larger communities, and it is practically out of the question in many sections of the country.

Chemical disinfection offers a means whereby a reasonable bacterial purification may be accomplished without complete purification of the organic matter. It is in no sense a substitute for sewage purification as ordinarily understood, for, though the application of chlorine compounds to an effluent oxidizes the organic matter in it to some extent and thereby increases its stability, such improvement is only incidental. It is not in anyway comparable with the cost of treatment, and it would be unwise to attempt to obtain stability in such manner. Incidentally, however, the advantages of this increased stability are obtained, and it is probable that rapid sewage filters may be worked at somewhat higher rates and with less margin for safe operation where chlorine treatment is employed as a finishing process. Under certain conditions it may be found desirable to effect bacterial removal without organic stability; along the seacoast and possibly along some great rivers of the Middle West the dilution factor is sufficienty high to preclude the danger of physical nuisance. Under other conditions the production of a stable effluent without regard to the amount of organic matter discharged may suffice; under others the removal of suspended matter may be of prime importance. Due consideration should be given in any particular process to the character of the organic matter in the effluent, and further treatment is advisable, not only where the discharge produces, or threatens to produce, an actual physical nuisance, but wherever the self-purifying powers of the stream will be appreciably drawn upon. In other words, stability is demanded in all effluents, unless the dilution is very great, not only in relation to the local discharge, but also in relation to all the sewage or effluent that the body of water in question may receive. This much is demanded from the standpoint of physical pollution alone. If, therefore, bacterial removal is also essential, disinfection is particularly satisfactory as a finishing process, because it can now be conducted at far less cost than the cheapest form of supplementary sand filtration.

Comparison on a cost basis of the methods of chemical disinfection makes it apparent that chlorine in some form is the most efficient agent, though it must be admitted that the possibilities of heat and of certain organic compounds have not received adequate investigation. Calcium hypochlorite, or commercial bleaching powder, is by far the most satisfactory chlorine compound available. It has greater germicidal efficiency than equivalent amounts of free gaseous chlorine, chlorates, or perchlorates. It is equaled in efficiency by potassium and sodium hypochlorites, the products of certain electrolytic cells. The electrolytic production of hypochlorites or of free chlorine is not a satisfactory source of the disinfectant. The cost of such manufacture, on a scale necessarily small even at the larger sewage-disposal works, is at present so little below the cost of bleaching powder that no safe margin is left to cover the additional responsibility and uncertainty that are involved. Improved processes of manufacture may alter conditions somewhat, but the highest possible working efficiency and the cheapest power would not sufficiently reduce the costs to alter these general conclusions.

The application of 3 parts per million of available chlorine in the form of bleaching powder to a trickling-filter effluent similar to those on which experiments were made effects satisfactory disinfection. The removal of bacteria from the effluent averages over 95 per cent, making the removal for the whole purification process 98 to 99 per cent of the number in the crude sewage. The cost of disinfection ranges from $1 to $1.50 per million gallons of sewage, depending chiefly on the size of the plant. Effluents of higher degrees of purity can be disinfected at still lower cost. Five parts per million probably represents the maximum amount of chlorine required for the treatment of trickling-filter effluents of poorer quality. The results obtained with the amounts of disinfectant that are specified do not, of course, amount to complete sterilization, but they may reasonably be called "practical disinfection." Considerable additional cost is required to improve them but slightly.

The disinfection of crude sewage to the same final condition requires the removal of over 98 per cent of its total bacteria. This may be accomplished by the application of from 5 to 10 parts per million of available chlorine, the amount depending on the character of the sewage. Such disinfection costs from $1.50 to $3.50 per million gallons.

The disinfection of septic sewage requires the application of from 10 to 15 parts per million of available chlorine. If no further purification is required than that given by septic action and by disinfection, it is advantageous to reverse the processes by disinfecting the crude sewage before it enters the tank. The resulting development of saprophytes within the tank has no sanitary significance, and it is doubtless of great advantage in the subsequent purification of the organic matter in the stream.

The removal of *B. coli* is usually somewhat more complete than that of the total organisms. Under the conditions of a laboratory experiment, the results of hypochlorite disinfection on typhoid and colon bacilli in tap water were identical. It seems reasonable to assume, therefore, that the viability of the typhoid organism under working conditions in practical sewage disinfection is at least no greater than that of the colon bacillus and no greater than that of the sewage bacteria as a whole. Consequently the disinfection results obtained with total bacteria may, in the case of chlorine disinfection at least, be referred directly to the typhoid bacillus with assurance of reasonable accuracy.

The results obtained in this investigation are so much more favorable than any results that have been reported for similar work that comment on their accuracy and general applicability seems justifiable. The more important portions of the work have been practically duplicated under as diverse conditions as possible and by different workers. There is no apparent reason for believing that the results are not of general applicability. The reactions involved are particularly free from interference on the part of the mineral constituents of normal sewage, a condition which has not been found where copper has been used as the disinfectant. The satisfactory results in the present work are largely due to the fact that many little difficulties inherent in new processes have been overcome by continuous work extending over considerable periods of time, and in particular to the fact that the experiments were made part of permanent laboratory routine and were free from temporary and special characteristics which usually involve discontinuity and interruption. This routine continued week after week without interruption and without undue attention—in fact, just as it would naturally go on in practice. It is believed that the results represent what may be accomplished in practice and that they can be duplicated under working conditions on any scale which may be desirable.

PUTRESCIBILITY AND STABILITY OF SEWAGE EFFLUENTS.[a]

INTRODUCTION.

The development of modern rapid processes of sewage treatment, involving the use of coarse material, has resulted in a somewhat changed conception of the functions of sewage disposal, while the general introduction of contact and trickling filters in the newer and larger works has made it necessary to examine methods of sewage analysis from a new viewpoint. Certain hitherto important features of the analysis have assumed comparatively unimportant rôles, and new determinations have been developed on which the chief reliance is now placed. In the older methods of sewage purification, almost complete removal of organic matter and oxidation of the nitrogen were obtained, and the analytical methods employed in the control of such plants were designed to test their efficiency in accomplishing these ends. Consequently the determination of nitrogen in its different stages of oxidation and of organic matter in general were paramount. These determinations are only of minor importance in the practical control of modern rapid filters, where oxidation of nitrogen is incidental and removal of organic matter is but slight. Suspended solids, available oxygen, and the character of the effluent in reference to its stability now demand first consideration. As the production of a stable effluent is the primary function of such filters, the determination of stability becomes the most important analytical method in filter control. This point has been generally recognized, and incubation or putrescibility tests of one form or another are in general use, often at places where no further analyses are made. It unfortunately happens, however, that there are many different conceptions of what putrescibility really is and many different methods of determining it. Consequently statements of results lose much of their significance and comparisons are difficult or impossible. The present article is a review of the subject for the purpose of establishing the fundamental facts and of harmonizing current opinions. A method of determining stability, which has been in use by the writer for nearly three years, and a numerical method of expressing results, by which quantitative value is given to the test, are also presented.

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[a] Investigation made at the sanitary research laboratory and sewage experiment station of the Massachusetts Institute of Technology.

PUTRESCIBILITY.

Putrescibility, as applied to organic matter in general, implies the ability of that matter to undergo offensive putrefactive decomposition. In a strict sense putrefaction is a term applied to nitrogenous matter only, though this is a popular rather than a logical conception. Exactly what constitutes offensive putrefactive decomposition in a sewage effluent is a matter on which opinions differ. Such decomposition is always anaerobic, and it is usually accompanied by the evolution of offensive odors. These two phenomena have, therefore, formed the basis of most putrescibility tests. Some criteria of putrefaction which have been employed are: (1) Development of offensive odors; (2) formation of black sediment; (3) reduction in the amount of dissolved oxygen; (4) loss of all dissolved oxygen; (5) loss of all available oxygen, including that of nitrates and nitrites; and (6) increase in the oxygen-consumed figure. Some of these tests are based on partial reduction of the available oxygen in the effluent; others depend on the complete reduction of the available oxygen and subsequent anaerobic fermentation. The tests most commonly employed belong to the latter group, depending on the production of odor or of hydrogen sulphide, blackening of the liquid, or reduction of organic dyes. The test which depends on an increase in the oxygen-consumed figure during incubation is also in that class, because anaerobic fermentation alone renders organic matter more readily oxidizable.

These two types of test illustrate two distinct points of view which should be clearly differentiated. An effluent may be regarded as being composed of a given mass of organic matter dissolved or suspended in a definite amount of water. The water contains also a definite amount of available oxygen in the form of free dissolved oxygen, nitrites, nitrates, and possibly of other compounds. All the organic matter is oxidizable to some extent, and to that extent it serves as bacterial food. The greater the amount of organic matter and the greater its oxidizability, the greater is the absorption of oxygen from the medium. Consequently a reduction of available oxygen in the effluent during incubation is a measure both of the amount of organic matter present and of its capability of oxidation. As a small amount of readily oxidizable matter has the same effect on the result as a larger amount of more stable matter, a test of this kind indicates whether or not the organic matter consumes oxygen; but it does not show whether or not the supply of available oxygen is sufficient to prevent the establishment of anaerobic conditions. This important question of the balance between the oxygen demanded by the organic matter and the oxygen available in the liquid is taken into consideration by tests of the second kind mentioned, namely, those dependent on the establishment of anaerobic conditions. Such tests do not involve estimation of the amount and the kind of organic matter; indeed, organic matter which does not absorb any oxygen from the liquid under the conditions of an incubation test must be very highly oxidized; and, furthermore, most organic matter derived from sewage is putrescible in itself—that is, if it is stored by itself in the absence of oxygen, it undergoes putrefactive changes. The question at issue is not, however, whether the organic matter itself will putrefy, but whether the effluent as a whole will become so reduced in oxygen that putrefaction will become possible. In other words, it is simply a question of a balance between the available oxygen of the effluent and the oxygen which the organic matter will require during the incubation period. It would seem that the problem might readily be solved by determining this balance, but, unfortunately, it is not a simple matter, because the action involved is bacterial. Many attempts have been made to determine the oxygen balance analytically, but such tests answer only with very good and very bad effluents, for which an inspection of the sample would serve just as well. When there is doubt about the character of the effluent—the condition for which such information is of most value—all such analytical procedures have heretofore failed. It is evidently impossible to imitate with any degree of precision the bacterial activities that are involved. There remains, then, but one satisfactory expedient: To let the reaction proceed by itself and to note the result. But here also there are difficulties, because bacterial reactions of this sort are necessarily slow in reaching equilibrium, and the time required by a nicely balanced effluent is greater than can be allowed in routine work. Some arbitrary period of time, therefore, is usually adopted, and it is in respect to this factor that the confusion rises. If stability is to be considered a definite qualitative characteristic of an effluent, that characteristic should be determined by a test sufficiently prolonged to insure equilibrium, but such procedure is not feasible for obvious practical reasons, and it is not desirable, because it is not enough simply to know that the available oxygen is sufficient or insufficient to satisfy the demands of the bacteria that are working on the organic matter. If the available oxygen is sufficient, there is perfect stability—a definite condition; if it is insufficient, there is still stability in the quantitative sense—a relative stability determined by the relation of the available oxygen to the total amount of oxygen required by the organic matter for perfect stability. In practice the latter condition is the one usually encountered.

RELATIVE STABILITY.

DEFINITIONS.

The term putrescibility has had so many and so varied meanings in dictionaries, in popular parlance, and particularly in the minds of water chemists, that it is proposed to employ the word *stability* for that desirable quality which is the usual object of sewage purification—the transformation of the organic matter to such form that it is incapable of undergoing offensive putrefaction. This term has the added advantage of implying a positive characteristic that is acquired during purification, and it conveys a much more definite impression of the thing under discussion than the negative term *putrescibility.* A few more definitions are necessary in order to simplify the discussion. The time required to establish anaerobic conditions in an effluent which, on incubation in a closed bottle, is subject to bacterial activities producing such conditions may be called for brevity the *reducing time;* the total amount of oxygen initially present in the form of free dissolved oxygen, nitrites, nitrates, and possibly other combinations may be called *available oxygen;* the term oxygen required for equilibrium or simply *required oxygen* may be understood to express the total amount of oxygen which would be consumed by bacterial action in the effluent if the latter were supplied with an unlimited amount of oxygen and if the reaction were allowed to proceed to a condition of substantial equilibrium. An effluent of the character under discussion is not stable in the absolute sense, because its available oxygen is less than the oxygen required for equilibrium; but, of two such effluents, that one is obviously the better which contains the greater amount of available oxygen in proportion to its required oxygen. In other words, effluents of this class have a certain relative stability which is indicated by the ratio of the available oxygen to the required oxygen. This relative stability, as will be shown, can be measured by the time required to reach the anaërobic stage. The term *stability* without qualification is employed in this paper to describe that condition in which the available oxygen exceeds the required oxygen, and the term *relative stability* is used to indicate the character of the effluent in the sense suggested. A perfectly stable effluent, therefore, has a relative stability of 100 per cent.

It is apparent that time is an important element in stability tests, and that it is not compatible with the idea of relative stability to select an arbitrary period of time for establishing the line of demarcation between stability and putrescibility. It is obviously unfair to record one effluent as nonstable because it "holds up," or fails to putrefy, for only three days and to record another as stable because it "holds up" for four days. A filter might deliver during one week an effluent that would fail to pass a four-day incubation test by a narrow margin and might deliver during the next week almost crude sewage for four days and a passable effluent for three. Obviously, the first week's run would be the better and should be so recorded; but, under the present practice in many places, all the samples during the first week would be putrescible and 40 per cent of those during the second week would be nonputrescible. The first requisite, therefore, in logical study of the problem is that the time required for an effluent to reach a condition of anaerobic decomposition shall be taken as an index of its relative stability. This time element is absolutely indispensable, and any test that is adopted for the determination of relative stability should be of such a character that the length of time required for the sample to reach a given anaërobic condition may be recorded.

ESTIMATION OF THE REDUCING TIME.

Many tests have been devised to determine whether or not an effluent is putrescible, and a review of the subject with the details of the methods proposed has been given elsewhere.[a] In any determination of the time required to exhaust the available oxygen in an effluent the following conditions must be fulfilled: (*a*) The sample must completely fill the bottle, the stopper of which must be tight and must not be removed during the test; (*b*) determinations must be made at a standard temperature; (*c*) observations must be made at least as frequently as once a day. If a test is employed which necessitates opening the bottle in order to observe the condition of the sample, one bottle must be incubated for each day that the effluent is under observation. This is true for any test which depends on a chemical determination of any constituent or which depends merely on the odor developed. Obviously such tests are not well adapted to the conditions heretofore stated. A simpler procedure is one in which the anaerobic condition can be detected by the appearance of the effluent without opening the bottle. The anaerobic fermentation that occurs immediately after the complete exhaustion of the oxygen is usually accompanied by a production of hydrogen sulphide. Consequently an indicator that is sensitive to hydrogen sulphide is advantageous in detecting the beginning of the anaërobic fermentation. Fortunately delicate indicators are available for this purpose, for certain organic dyes are readily reduced to corresponding leuco-compounds under anaerobic conditions. Methylene blue is an organic dye of this character, and it is reduced to its colorless leuco base by hydrogen sulphide, alkaline sulphides, and by the

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[a] Phelps, E. B., and Winslow, C.-E. A., On the use of methylene blue in testing sewage effluents: Jour. Infectious Diseases, Suppl. No. 3, 1907, p. 1.

commercial reducers used in dyeing. Its employment for the study of stream pollution was first proposed by Spitta,[a] and it was later more thoroughly investigated by Spitta and Weldert[b] as a test for sewage effluents.

Methylene blue, or tetra-methyl-thionin chloride, is a commercial dye of complex constitution, having the empirical composition $C_{16}H_{18}N_5SCl$. Merck's medicinal preparation is pure and it is preferable to the commercial article for sewage work. It is an extremely sensitive indicator for hydrogen sulphide and other reducing bodies, being decolorized at once in the presence of even small traces; its decolorization by bacterial action has been studied by many observers, the principal of whom are cited by Spitta and Weldert.[c] The technique of its use in testing a sewage effluent is extremely simple. One cubic centimeter of a one-tenth per cent aqueous solution of the dye is added to the effluent in a glass-stoppered bottle of 250 cubic centimeters capacity, and the sample is then incubated either at 20° C. or at 37° C. The blue color of the solution remains practically unchanged till the available oxygen contained in it has been consumed and putrefactive conditions have been established. At this stage the dye is reduced and decolorized. The time required for such decolorization is, therefore, approximately the time required for the exhaustion of the available oxygen. The dye is an indicator for what may be called the oxygen neutral point, the point at which the available oxygen becomes exhausted and anaerobic conditions are established. Some studies[d] made at the sewage experiment station confirm the earlier conclusion of Spitta and Weldert, that the end point indicated by this dye is almost exactly the desired neutral point. The order in which different forms of oxygen are reduced appears to be: Dissolved oxygen, nitrates, nitrites, sulphates, and phosphates. Methylene blue was found to change color practically at the same time as the nitrites in this series. It is readily conceivable that an indicator might possess such properties that it would be reduced before the nitrates or even before the total exhaustion of the free oxygen. Another indicator might change only after the reduction of the sulphates. The fact of this varying end point has been well shown in a recent paper by Clark and Adams.[e] Comparative incubation tests were made with 17 dyes as indicators, only 6 of which were reduced during the incubation. Arranged in the order of their reducibility these are: Indigo carmine (sulphonated indigo), methyl-

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[a] Archiv. für Hyg., 1903, vol. 46, p. 113.

[b] Spitta and Weldert, Mitteilungen aus der Königlichen Prufungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 6, 1906, p. 161.

[c] Loc. cit.

[d] Phelps, E. B., and Winslow, C-E. A., On the use of methylene blue in testing sewage effluents: Jour. Infectious Diseases, Suppl. No. 3, 1907, pp. 1-13.

[e] Clark, H. W., and Adams, G. O., Studies in incubation tests: Jour. Am. Chem. Soc., vol. 30, 1908, p. 1037.

ene green, and methylene blue; and then, order not stated, congo red, methyl orange, and tropæolin. The average time computed from 26 tests for the reduction of indigo carmine was 2 days; for methylene green the average time was 2.4 days; and for methylene blue, 3.9 days. As it is of course impossible to hasten or to retard the reactions that are taking place, these differences show differences in the end point recorded by the several indicators.

In the writer's experiments it was shown that the end point indicated by methylene blue is probably that point at which the free oxygen and the nitrates are practically exhausted and reduction of the sulphates is just beginning. This is understood to be the point at which anaerobic conditions are established. The work was not undertaken, however, for the purpose of determining the end point accurately, and it is possible that the end point of methylene blue is a little too far along and that either methylene green or indigotin indicates the desired point more closely. Just as it is essential in other branches of analysis to specify the indicator that shall be used in a given determination, in order to prevent confusion in comparative work, similarly it is important in this test to adopt a standard indicator as a basis of comparison. The results of all experiments thus far are in favor of methylene blue, and that dye is now widely and satisfactorily used in the laboratories of the country; consequently, its retention as a standard appears advisable, at least until further experimental evidence is available. The present series of comparative stability values is calculated on the assumption that methylene blue be used. A change in the final end point adopted would, of course, necessitate a remodeling of the computations.

THEORETICAL RELATION BETWEEN REDUCING TIME AND RELATIVE STABILITY.

The time required for complete exhaustion of the oxygen from an effluent—the reducing time—is obviously not a simple function of its relative stability; but there is a well-known theoretical relation between velocity of reaction and amount of reacting substance, from which it is possible to compute one from the other. It is a principle of physical chemistry that the velocity of a chemical reaction is a function of some power of the concentrations of the reacting substances. In the simplest cases the velocity varies directly as the concentration. The bacterial reactions that have been investigated also conform to this law,[a] and it has been, therefore, applied to

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[a] Chick, H., An investigation of the laws of disinfection: Jour. Hyg., vol. 8, 1908, p. 92.

Lubenau, C., Zur Saürebildung der Diphtheriebazillen: Arch. f. Hyg., vol. 66, 1908, p. 305.

Famalener, W., and Madsen, T., Die Abschwächung der Antigen durch Erwärmung: Bichem. Zeitung, vol 11, 1908, p. 186.

Nawiasky, P., Uber die Umsetzung von Aminosaüren durch *B. proteus vulgaris:* Arch. f. Hyg., vol. 66, 1908, p. 209.

the present study. The exact expression of the function need not be detailed, for it can easily be seen that this general law is approximately applicable; if one-half the work of oxidation is accomplished in one day, the availability of the organic matter as a food supply is reduced one-half, and the consequent bacterial activity on the organic matter is reduced accordingly; at the beginning of the second day food supply and bacterial activity are in the same relative proportions and the same relative amount of work is done again; that is, one-half of the remaining work of oxidation will be done during the second day. This law is expressed by the following equation:

$$\log. x = \log. a - k^t$$

in which a is the amount of oxygen required for equilibrium at the commencement of the action, and x is the amount similarly required at the end of the time t, while k is a constant known as the velocity constant. If a grams of oxygen are required for initial equilibrium, and if x grams are required after the sample has been incubated in a tight bottle for a period of time which may be termed t days, $(a-x)$ grams of oxygen have been abstracted from the liquid by the organic matter. If the available oxygen of the liquid has just become completely exhausted at the end of t days, the value $(a-x)$ represents the amount of available oxygen originally present in the sample. It is not even necessary to know the actual amounts of oxygen, because the ratio of available oxygen to the oxygen initially required for equilibrium gives a relative stability factor that obviates the expression of the actual amounts. The ratio is

$$\frac{a-x}{a}$$

The value of this expression in terms of t and k can be found by using the logarithmic equation given above:

$$\frac{a-x}{a} = 1 - k^t$$

The second term of this equation, therefore, is equal to the ratio between the total available oxygen and the oxygen required for equilibrium, the ratio being expressed in terms of a constant and the reducing time. This ratio is the relative stability.

If a and x could be determined by analysis it would be possible to determine the value of k by a few tests. It has already been shown, however, that there is no simple chemical method of determining the amount of oxygen which is consumed by the organic matter under natural conditions. A possible method involves actual measurement of the amount of oxygen absorbed by the liquid in a time sufficiently prolonged to insure virtual equilibrium. If, however, k is determined only approximately and if a series of values for $(1-k^{t})$ is obtained for all values of t, the terms of this series bear practically a constant relation to each other, even if k is varied considerably. The number expressing the relative stability is, in any case, a true index of the character of the effluent, independently of the further requirement that it shall be the absolute ratio of the available oxygen to the required oxygen. If it is not this absolute ratio it stands in constant but unknown relation to it.

An indirect method has been devised for determining the value of k with a degree of accuracy which is ample for the present discussion. For this purpose the results of 2,649 separate stability tests have been analyzed. The nature of these samples and the manner of determining the reducing time t is described on pages 78 to 80. It is sufficient to state that the reducing time was from one to twenty days in most of the tests, while many of the samples showed a relative stability of more than 100 per cent. As the samples which required a reducing time between one and twenty days had relative stabilities ranging from zero to 100 per cent, it was assumed for the purpose of approximating the value of k that one-half had values less than 50 per cent and one-half values greater than 50 per cent. Such assumption, of course, is justifiable only with a large number of observations, but it is believed that it is sufficiently accurate in the present case. Inspection of the tabulated results showed that a stability of 50 per cent was attained, at a temperature of 20° C., in almost exactly three days, thus making

$$1-k^{3}=0.50; \text{ or } k=0.794.$$

If this value of k is substituted in the equation before mentioned, the following values of the relative stability corresponding to the time t in days are obtained.

TABLE 1.—*Relation between reducing time and relative stability at 20° C.*

Reducing time in days. (t.)	Relative stability. $(1-0.794^{t}.)$	Reducing time in days. (t.)	Relative stability. $(1-0.794^{t}.)$
1	21	9	87
2	37	10	90
3	50	11	92
4	60	12	94
5	68	14	96
6	75	16	97
7	80	18	98
8	84	20	99

These values of relative stability are strict measures of the character of the effluent. An effluent which contains more than sufficient oxygen to establish stability should have a stability of 100; in other words, it would never reach the anaerobic stage. In practice it is necessary to set some time limit to the tests and give an average stability value to all tests exceeding this limit. This value is sufficiently high to indicate the character of the effluent. On the other hand, crude sewage containing a little dissolved oxygen is completely reduced in one or two hours, or, if it contains no dissolved oxygen, decolorizes methylene blue at once; in numerical expression its relative stability is practically zero. These figures are comparative, because they may be added and divided to obtain periodical averages and the averages thus obtained are properly weighted. This is not so if the reducing times themselves are averaged. The figures are also an approximate measure of the ratio between the total available oxygen in the effluent and the amount of oxygen required for the production of stable equilibrium in the organic matter, and it is believed that the approximation is sufficiently close for ordinary purposes of interpretation.

DETERMINATION OF RELATIVE STABILITY.

INCUBATION PERIODS.

Relative stability as previously defined is a numerical measure of the relation between available oxygen and required oxygen and it is also a function of the reducing time. Some practical applications of the stability values in Table 1 remain to be outlined.

Incubation periods exceeding five days are inconvenient and probably unnecessary in practical work, but in experimental work where more detailed knowledge is desired, longer periods may be used to advantage. At the sewage experiment station, a fourteen-day period has been adopted. During the past two years tests have been made of more than 2,600 samples of trickling-filter effluents of such a quality that most of them were near the border line between satisfactory and unsatisfactory effluents. Most of them were on the safe side, but some of them were unsatisfactory for considerable periods. The results of this large number of tests, therefore, constitute an admirable basis for studying the advisability of using shorter periods of incubation. In the summary of the results in Table 2 the tests are divided first in ten groups corresponding to the different filters and the years during which the tests were made. Effluents A, B, C, and D are from trickling filters before sedimentation; E and F are the same effluents after two-hour sedimentation. The results in each group are subdivided in order to show the per cent of the number of samples that retained available oxygen at the end of stated periods. The results shown in this table have been platted and from the plats the number of samples which would have retained available oxygen after twenty days have been determined by exterpolation from a plat of the results for shorter periods of time.

TABLE 2.—*Summary of stability tests of trickling-filter effluents, showing time required to exhaust the available oxygen.*[a]

Effluent.	Period.	Number of samples tested.	Per cent of samples retaining oxygen after—									
			1 day.	2 days.	3 days.	4 days.	6 days.	8 days.	10 days.	12 days.	14 days.	20[b] days.
A	1906–7	388	91	83	75	67	58	54	48	45	42	35
B		388	93	87	81	76	67	62	58	56	53	45
C		388	97	91	86	83	78	74	72	70	70	69
F		388	97	93	91	88	84	81	77	74	73	71
A	1907–8	223	38	32	28	25	22	20	17	15	15	14
B		225	39	31	25	22	14	9	6	5	4	3
C		212	29	19	12	6	5	4	3	3	2	1
D		189	17	5	1	1	0	0	0	0	0	0
E		38	50	37	21	11	5	5	2	0	0	0
F		210	20	14	10	6	3	2	1	1	1	1

[a] Indicator, methylene blue; temperature of incubation, 20° C.

[b] Values exterpolated.

If it is assumed that in practice an incubation period of four days at 20° C. will be employed, it is possible to show from the data in Table 2 what relative stability values should be assigned to samples that retain some available oxygen after four days. Such samples may be divided into two hypothetical groups, namely, those which would have lost their oxygen between four and twenty days and those which would have retained it more than twenty days. Obviously a relative stability of 100 may be assigned to the latter because the value at twenty days is 99. An average time of ten days may be selected for the period between four and twenty days, thus making proper allowance for the decreasing number of samples, which reduce each day, and a relative stability of 90 may be assigned to that group. Between 43 and 63 per cent of the samples which passed the four-day period were reduced before twenty days. This per cent varied with the quality of the effluent, but it may be taken as 50 per cent without introducing an error of more than 5 per cent in the final result in any group. For practical purposes it may be assumed that one-half of all tests passing a four-day period of incubation will be reduced before twenty days, or in an average time of ten days, and that one-half will exceed twenty days. This gives 95 for an average relative stability value of the whole number of samples. If a four-day period of incubation at 20° C. is adopted, each sample reduced on the first, second, third, or fourth day may be recorded as having a relative stability of 20, 37, 50, and 60, respectively, and all samples retaining available oxygen after four days may be given a relative stability of 95. An individual result obtained in this manner will have but little accuracy, and when only a few tests are made, an incubation period of at least 10 days should be employed. On the other hand, when daily tests are made, the method outlined will give for monthly periods average results that are very close to the truth. Relative stability values calculated from the data in

Table 2 for the entire twenty-day period of incubation are compared in Table 3 with similar values obtained by the shorter, four-day, method. The agreement is satisfactory. If smaller numbers of tests are considered, the distribution naturally will not be so regular and greater errors will be introduced in the results calculated. In order to determine the accuracy of the proposed method, the first 776 samples of Table 2 have been subdivided into twelve quarterly groups, containing from 36 to 78 samples in each group, and the relative stability values have been calculated for these smaller groups, as shown in Table 4.

TABLE 3.—*Comparison of relative stability results obtained from the twenty-day incubation period shown in Table 2 with those calculated from a four-day period.*

Effluent.	Period.	Relative stability.	
		20-day period.	4-day period.
A	1906–7	76	77
B		81	82
E		88	86
F		86	84
A	1907–8	43	43
B		39	41
C		31	31
D		25	25
E		38	39
F		28	28

TABLE 4.—*Comparison of relative stability results obtained from smaller numbers of samples by the use of four, six, and twenty day incubation periods.*

Effluent.	Quarter.	Number of samples averaged.	Relative stability based on a—		
			4-day period.	6-day period.	20-day period.
A	1906.				
	First	37	59	59	58
	Second	73	57	53	52
	Third	59	64	61	60
	Fourth	77	89	88	88
	1907.				
	First	74	92	92	92
	Second	68	91	91	92
B	1906.				
	First	36	62	61	59
	Second	71	75	69	69
	Third	59	81	79	82
	Fourth	78	86	84	90
	1907.				
	First	75	91	90	95
	Second	69	91	90	93

The maximum error with the smaller groups is about 10 per cent, and this error can be materially reduced by basing the calculation on a somewhat longer incubation period. The second column in Table 4 shows the relative stability values calculated from a six-day period, and the maximum error in this computation is less than 5 per cent. If the greater number of the samples of a well-purified effluent retain oxygen after four days, the results with any short method of calculation will be low. Since a value of over 95 can not be obtained with this method, it is obviously impossible to provide a four or six day method which will give accurate results. If more accurate information is necessary, longer periods of incubation—perhaps as long as ten days—are advisable. It matters little, however, whether the relative stability is 95 or 99, as far as practical results are concerned, because either value represents a high degree of purification.

EFFECT OF TEMPERATURE ON THE REDUCING TIME.

It has been assumed in the foregoing discussion that the temperature of incubation is 20° C., and there are certain reasons why this temperature is better than higher ones. It probably represents more nearly than any other the average temperature of streams, and results depending on bacterial activity should be obtained near the normal temperature to which the bacteria are exposed in nature. Incubations at 37° C., for example, probably cause the development of a class of bacteria quite different from those normally at work. The most serious objection to higher temperatures, however, is the fact that certain effluents, particularly those from the rapid filters which are in such common use, contain a large amount of dissolved oxygen, frequently 8 or 10 parts per million, and this represents the greater part of the available oxygen. At 20° C. 9 parts per million of oxygen is the saturation point. The saturation point at 37° C. has not been determined, but it is not over 7 parts per million, so that there is a tendency for some of the dissolved oxygen to escape at high temperatures. Tight stoppers will not prevent the escape of this released gas unless great care is taken with them, and mercury seals are hardly adapted to routine work. It is therefore practically impossible properly to maintain the necessary saturation conditions at a temperature higher than 20° C. A variation of temperature with season would have certain advantages, but such adjustment is rather impracticable. Since results are frequently obtained at 37° C., the relation of such results to those obtained at 20° C. has been investigated and has already been reported.[a] Variable relations were found, as was expected, but the average results may be used with some degree of accuracy. It was found that the time of reduction at 37° C. was from 37 per cent to 72 per cent of that required at 20° C., and the mean of 20 determinations was exactly 50 per cent. Carefully fitted glass stoppers were used in the bottles, and ordinary precaution was taken to prevent loss of

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[a] Phelps, E. B., and Winslow, C. E.-A., loc. cit.

oxygen. If haste is necessary, a temperature of 37° C. will give results in about one-half the time required at 20° C. But the use of a temperature of 20° is strongly recommended whenever it is possible to employ it.

SUMMARY OF METHOD.

Samples should be collected in glass-stoppered bottles of 150 or 200 cubic centimeters capacity. No special precautions are necessary in collecting samples of ordinarily good effluents that are fairly high in dissolved oxygen. If the dissolved oxygen is low, precautions similar to those used in collecting dissolved oxygen samples should be observed. A one-tenth per cent solution of methylene blue, preferably Merck's medicinal quality, is used as indicator. One cubic centimeter of this solution is added to each of the samples, which are then incubated, preferably at 20° C., for four days, and observations are made at least once a day. The samples in which the methylene blue becomes decolorized are recorded as having a relative stability corresponding to the time required for reduction. Those that are blue at the end of four days are given a relative stability value of 95.

Table 5 gives the relation between time for reduction and the relative stability. Though the figures up to four days are the only ones required, the entire series up to twenty days is given for comparison. Relative figures for incubation at 37° C. also are given, but the use of that column is not recommended, except when it is absolutely necessary to use the higher temperature, or when it is desired to convert results to a standard basis of 20° C.

TABLE 5.—*Relation between relative stability and reducing time at 20° and at 37° C.*

Relative stability numbers.[a]			Relativc stabilty numbers.[a]		
t_{20}.	t_{37}.	s.	t_{20}.	t_{37}.	s.
0.5	....	11	8.0	4.0	84
1.0	0.5	21	9.0	4.5	87
1.5	....	30	10.0	5.0	90
2.0	1.0	37	11.0	5.5	92
2.5	....	44	12.0	6.0	94
3.0	1.5	50	13.0	6.5	95
4.0	2.0	60	14.0	7.0	96
5.0	2.5	68	16.0	8.0	97
6.0	3.0	75	18.0	9.0	98
7.0	3.5	80	20	10	99

[a] s=Relative stability or ratio of available oxygen to oxygen required for equilibrium. Expressed in per cent.

t_{20}=Time in days to decolorize methylene blue at 20° C.

t_{37}=Time to decolorize at 37° C.

Theoretical relation—

$s=100\ (1-0.794^{t_{20}})$

$=100\ (1-0.630^{t_{37}})$

INTERPRETATION OF RESULTS.

The arbitrary tests for putrescibility now employed require no interpretation. An effluent is either putrescible or nonputrescible, according to whether it is on one side or the other of a certain line of demarcation. The fact that the dividing lines, for there are many of them, are perfectly arbitrary and have no real significance seems to have been overlooked. Fixed arbitrary standards in sewage analysis are undesirable in that they relieve the analyst of the important and difficult duty of interpreting his own results in the light of his own peculiar environment. Some general observations and rules may be stated for aid in interpretation, but it should always be borne in mind that such interpretations are dependent as much on outside conditions as on the analyses themselves. The mere statement, therefore, that 75 per cent of the samples of a tested effluent were nonputrescible has no bearing whatever on the broader phases of interpretation. These facts are well known and accepted in ordinary analytical features. The aim of the present investigation has been to place the important determination of stability on the same basis. Under this proposed method of determining relative stability an interpretation of the information in hand is rendered possible. A relative stability of 75 per cent means that the effluent in question contains a supply of available oxygen equal to 75 per cent of the amount of oxygen which the effluent will eventually require before it will have become perfectly stable. The amount of this available oxygen is estimated fairly well by the chemical determination of dissolved oxygen and nitrates. The nitrites are usually so low that they are negligible, and it is unnecessary to decide whether or not the nitrates represent available oxygen, because they have been included in the test and must be considered in the interpretation. Undoubtedly the nitrates will not be used in the stream until the dissolved oxygen of the water has been reduced to a low point. Nevertheless, the fact remains that the available oxygen in the effluent, including the nitrates, is 75 per cent of that required for equilibrium, and that the remainder must come from the water of the stream, which must also supply enough additional oxygen to replace that which may be abstracted from the nitrates of the effluent, if aerobic conditions are to be maintained. Analyses of water from the stream and estimates of the relative volumes of the stream and the effluent complete the data necessary for a full interpretation.

In general, effluents having a relative stability greater than 90 per cent may be discharged into any stream without danger of their consuming any of the oxygen of the water, because effluents of such high stability will retain oxygen indefinitely on exposure to the air.

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